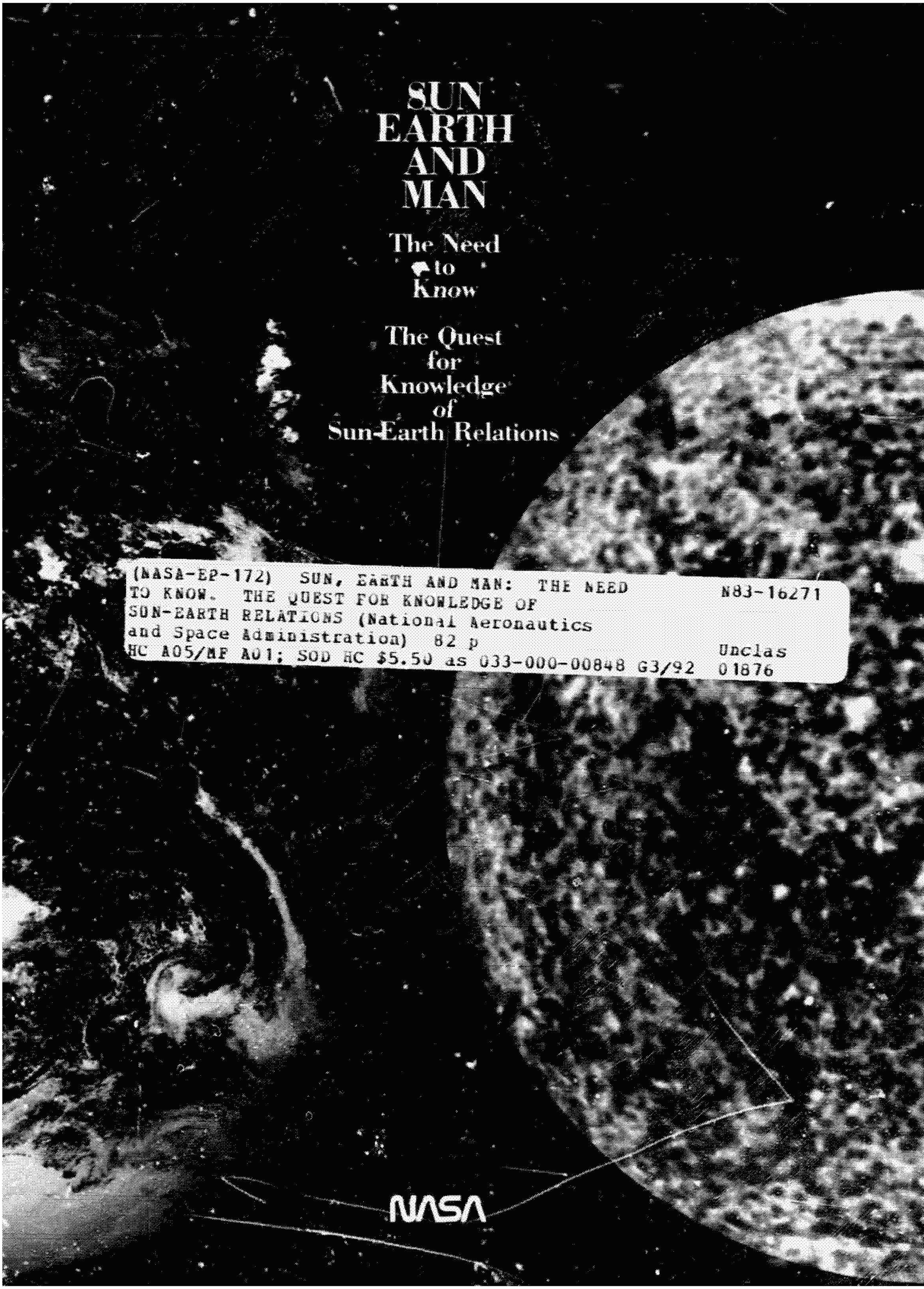


SUN EARTH AND MAN

The Need to Know

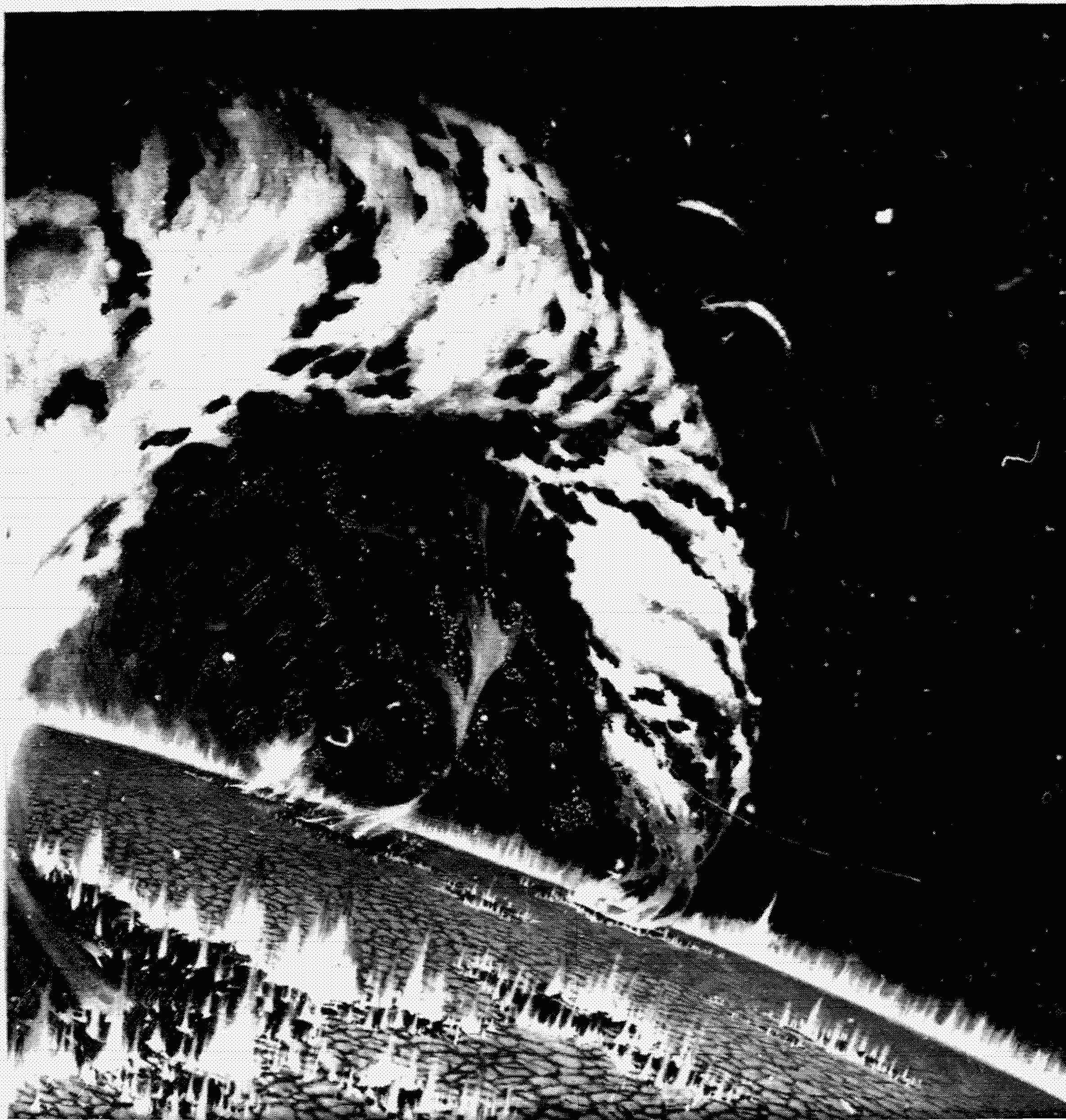
The Quest for Knowledge of Sun-Earth Relations

NASA

EARTH and MAN

The Need to Know

The Quest for Knowledge of Sun-Earth Relations



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INTRODUCTION

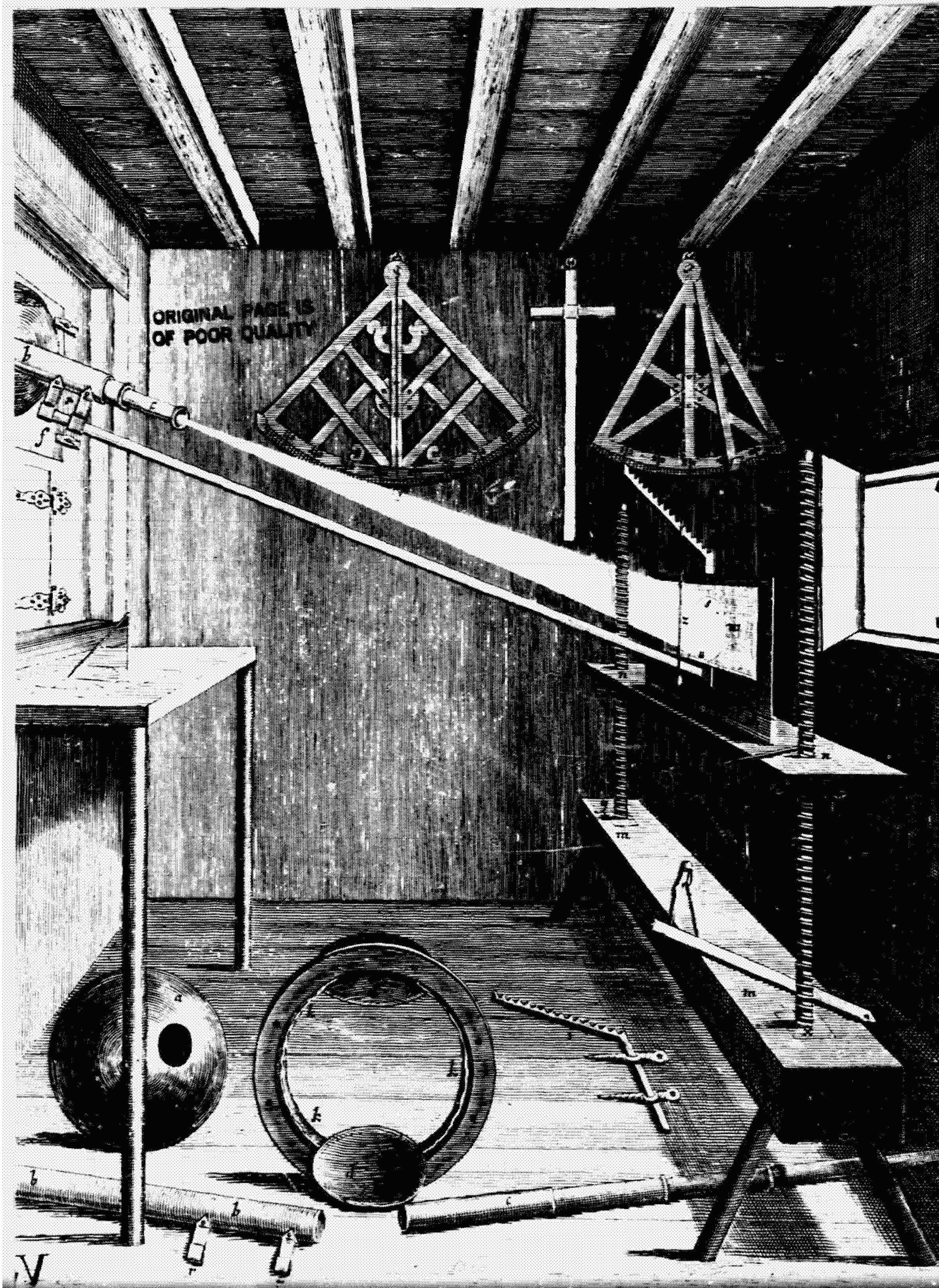
In the most basic sense, what we are doing is what we, as human beings, have always done—seeking knowledge, seeking to know. Somewhere at our species' core is a special need to know—know ourselves, know our planet, know the Universe if we can. We have always taken great risks, committed huge resources to add to the sum of our knowledge. Over the centuries determined people have voluntarily risked their lives to explore the Earth's most hostile and inaccessible places: the poles, the peaks, the open oceans, the jungles and the deserts; they have descended into the deeps of the sea, risen in balloons to the stratosphere, and launched into space in tiny capsules on the tips of rockets. They have always gone into the unknown and made it known; they have always pushed the frontiers of human knowledge outward.

NASA Administrator
National Aeronautics and Space Administration
"Letter from Washington"
NASA Activities,
October 1977.

Left: An artist's conception of solar flares.

Contents page: Flaming solar gases in tight magnetic loops photographed from Skylab, August 14, 1973.

Title page: This dramatic painting by Davis Meltzer shows the mottled surface of the photosphere marked by dark sunspots and broken by flaming prominences shaped into coils by powerful magnetic fields. Such a scene may one day be recorded by the instruments of a proposed solar "Scorcher."



I

BEFORE SPUTNIK

An engraving of 17th century astronomical instruments from the book Machina Coelestis *by Johannes Hevelius, 1673*

In the winter of one of the middle years of the 1640's, for the first time in living memory or recorded history, the people of eastern and western Holland ceased to be divided by the great, shallow Zuider Zee that lay behind the mighty dikes which held out the North Sea—because that winter the Zuider Zee froze fast, and skaters and horse-drawn sledges could cross back and forth at will.

That same winter, across the English Channel, incredulous Londoners were driving their carriages the length and breadth of the frozen Thames.

Another strange thing that winter was the failure of the long, flaring, colored streamers of the Aurora Borealis to appear even once in the night sky. A few people wondered if the two unusual occurrences were somehow related. Perhaps, they thought, the sky had become too cold for the Northern Lights.

At the same time, European astronomers observing through early and primitive telescopes, noticed that the dark spots they had been studying on the Sun's surface were no longer there.

The next winter was the same. And the next. And the one after that. Frozen lakes and rivers and even arms of the sea itself like the Zuider Zee. No ribbons or banners of light in the northern skies. In time people became accustomed to the change. In all the lands of the temperate zones, both north and south,—in Prussia and Russia and China and Japan, and in the struggling colonies of North America,—they wore heavier, warmer winter clothing, they cut more wood to warm their homes in the longer winters. They learned to use the frozen waters as winter highways and playgrounds. Generations of children grew to maturity knowing no other kind of winter, knowing the awesome spectacle of the Aurora only through the memory of their parents, and only half believing. In the Alps the glaciers inexorably advanced, grinding farther out upon their moraines than at any time since the last major glaciation 15,000 years before.

Not only science but even literature has recorded this "Little Ice Age." It was the time of the fictional Hans Brinker of the Silver Skates who raced with his peers on the frozen canals of his native Holland as related by Mary Mapes Dodge in her famous novel of 1865.

Then suddenly, after some seventy years, a winter around 1715 was "normal," although not "normal" to the people of the time; the Aurora returned to the northern skies, the dark spots reappeared on the Sun, and pre-1645 winter temperatures, Northern Lights and sunspots have been the rule ever since.

On the high plains of North America, measurement of tree growth rings, and the testimony of human witnesses over a period approaching three centuries reveals that severe droughts have occurred with eerie regularity approximately every twenty to twenty-two years. This strange pattern has been observed and recorded without fail since the drought of 1815-18.

The most recent drought occurred in 1976, although slightly east of the generally accepted "high plains" area.

Just a century ago one of the technological triumphs of a vigorous young America still tapering off from its proud Centennial celebration was the newly completed telephone cable linking us to Europe across the North Atlantic. There was reason to be proud: stringing some 2500 miles of copper cable across the peaks, canyons and abyssal plains of the Atlantic was a major engineering accomplishment. And it worked. Most of the time. The trouble was that occasionally for a few hours or a day, it didn't work very well. Static from unknown sources unpredictably garbled callers' voices in one direction or the other. That problem has continued into recent times. On February 10, 1958, on the Bell System's cable from Clarenville, Newfoundland, to Oban, Scotland, callers in Europe were startled and puzzled to hear voices from the North American end distorted into alternate loud squawks and faint whispers while their own voices were received in normal tones.

On the same day Western Union had severe and prolonged interruptions on its North Atlantic telegraph cable with the clacking telegraph relays delivering mostly unintelligible gibberish.

Whatever the problem was, it had nothing to do with the fact that the affected calls were under water. Cables on land had similar mysterious interruptions. On the same day that Bell and Western Union had difficulty with their cables, Toronto, Canada, had a temporary blackout when circuit breakers tripped in an Ontario power station.

On March 24, 1940, Minneapolis, Minnesota, was virtually cut off from the outside world when 80 percent of its long distance telephone lines inexplicably went dead for several hours. On the same day an electrical blackout occurred in parts of New England, New York, eastern Pennsylvania, Minnesota, Quebec, and Ontario.

As recently as August 4, 1972, a link in the Bell System coaxial cable between Plano, Illinois and Cascade, Iowa failed completely for approximately half an hour, and on the same date a half-million-dollar power transformer suddenly exploded at the British Columbia Hydro and Power Authority.

Like telephone, telegraph, and power transmission cables, pipelines are very long, continuous, electrical conductors—and they too have had their share of unexpected, unpredictable and not readily explainable disturbances. In the early 1940's a new pipeline was constructed across the Isthmus of Panama with one end literally in each ocean. But even before the pipeline was placed in service, severe corrosion caused the failure of valves and other terminal facilities at both ends. An investigation showed that an electrical current of as much as thirty amperes was at times flowing from ocean to ocean, first one way and then the other, and going to ground at the terminals where the damage was occurring. The current was not the result of any human activity.

In the fall of 1957, U.S. Navy radar planes like this on patrol over the North Atlantic lost radio contact with their bases for several hours as a result of events on the Sun 93 million miles away.

Similarly, large, transient electrical currents not attributable to any man-made cause, are occasionally induced in the modern 800-mile Alaska pipeline. These currents can produce severe problems for the electronic systems which control and monitor the pipeline.

In September of 1957, United States Navy flight crews operating radar-equipped, early warning patrol planes over the North Atlantic suddenly and completely lost radio contact with their base and all shore stations for several hours. Their mission was to locate, track and report all aircraft headed toward North America. They could locate and track—but they could not report.

In February of 1979 something went wrong with radio transmissions at certain frequencies across the United States. Higher frequencies, used for short range or line-of-sight communications, suddenly carried messages for thousands of miles. A Los Angeles fire department dispatcher had his emergency radio channel jammed by conversations from the scene of a plane crash in West Virginia. At the same time lower frequencies used for long distance communications were only carrying for about 100 miles.

As diverse as all these happenings are,—in time and scope and space and nature—they are, in fact, closely related. They are related by the fact that all were associated with events occurring in a slowly rotating nuclear fusion furnace 150 million kilometers (93 million miles) away, called the Sun.

Consider the closeness of that relationship.

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Sun/Earth Relationship

Most scientists now agree that the Sun and the Earth were born at about the same time out of the gravitational contraction and condensation of the same cloud of galactic gas and dust about 4.6 billion years ago. The atoms which power the Sun and which compose the eyes and the brain with which you read these words all came from that same parental galactic cloud. And it was the same galactic cloud which in turn was composed in large part of elemental atoms from the interior of a prior generation of exploded stars. We and our Earth and our local star, the Sun, are literally made of the same elemental materials, forged in the furnaces of ancient stars.

Our Earth and the other eight planets and 42 known moons of our solar system are locked in an intricate and dynamic gravitational/centrifugal balance around the Sun, each in its own orbit, each different in its chemistry and characteristics, but all bathed in and dominated by the emanations from the Sun. These emanations do not consist simply of the light our eyes can see and the warmth our bodies can feel. Earth and all the planets and moons of the solar system swing and spin in their various orbits through a flood of invisible but hot and highly energetic electrically charged particles spewed out of the Sun at supersonic speeds and affecting them in a variety of ways, only some of which we are beginning to understand.

Although most of the planets, including Earth, have their own magnetic fields, like those of hugely scaled-up bar magnets, all are also affected, again in ways

A cloud of hot ionized galactic gas and dust like the one from which scientists believe the Sun and its planets, including Earth, were formed about 4.6 billion years ago. Here an infrared image has been superimposed on a black and white photograph to show the gas cloud (the Swan nebula) as it would appear through a large infrared telescope.

we are just beginning to understand, by the spinning magnetic field of the Sun.

On Earth, all life of every kind from the tiniest viroid to the largest whale, from blue-green algae to giant sequoia, including the human species itself, is fully and precariously dependent on the Sun. All life on Earth originated and evolved in its light and its warmth. All life on Earth would be forever extinguished by only a minor change in its radiance. A drop of only two percent in the 10,000 degree Fahrenheit surface temperature of the Sun would initiate a global glacial advance which would turn our beautiful blue planet into a giant, uninhabitable snowball in only fifty years. A rise of two percent would melt the icecaps of Greenland and Antarctica, flood the continental coasts and eventually sear the land masses of Earth to Saharan stillness and sterility.

Today there are books and articles and television specials and news reports and bumper stickers: all concerned with something presumably just recently discovered--solar energy. The fact is that our Earth and all the life on its surface and in its seas have *always* been powered by solar energy. There are only a few kinds of energy on our planet that are *not* solar: e.g., geothermal (heat from the deep interior of the Earth); tidal (the ebb and flow of the tides caused by the gravitational pull of the Moon): and nuclear. Oil, gas and coal all come from the fossils of plants which grew by converting sunlight to energy. Wood and "biomass" are from the same source but more recent. Hydroelectric power is possible only because the Sun evaporates the Earth's standing water and pours it back in rainfall into the sources of the rivers which drive the water turbines. Even the wind that turns our windmills—and modern windmills or "wind turbine generators" hold great promise as a clean, renewable energy source—are born out of the uneven heating of the Earth's atmosphere by the Sun. In all the centuries before the Industrial Revolution, the animals which provided power and transportation not only existed because they had evolved in the life-giving Sun, but derived the energy used in their work from the plants (oats, hay, barley, corn) which had synthesized the Sun's energy to grow.

And there is good reason to hope that in the centuries to come, we will have the vision and will develop the technology to make direct use of the abundant solar energy outside the atmosphere of Earth for the long-term benefit of mankind.

In ultimate confirmation of the closeness of their relationship, Earth and Sun will one day die together as they were born together. Some five billion years in the future the Sun will begin to exhaust the hydrogen fuel in its deep interior and the fusion process will move outward, expanding the Sun into a red, giant star which will engulf and incinerate the inner planets, probably including the Earth. But there is no comfort in that "probably," because even if it is not physically swallowed by the swollen Sun, our planet will by then long have been a charred and lifeless cinder swinging residually through space.

A modern wind turbine generator powered by the uneven heating of the Earth's surface by the Sun which causes the winds. This one is on Block Island, Rhode Island and provides enough electricity for about 50 homes.

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This painting shows five stages in the life cycle of the solar system. The cloud of cosmic gas and dust from which the Sun and its planets were formed is at the top. The contraction of the cloud to form the embryonic solar system is just below, next appears the early solar system with the Sun's fusion furnace ignited and the planets beginning to cool. At the bottom is the solar system as we know it today, and in the lower left the Sun of some five billion years from now as a giant red star consuming the inner planets.

The Sun will not last long as a red giant. It will pulsate slowly a few times, expanding and contracting every few thousand years, spewing about half of its mass out into space, then shrinking to a white-hot dwarf before cooling to its ultimate condition, a dense and dead black lump lost forever in the galactic dark.

Mankind is literally part of Earth, constructed entirely of the chemicals in its crust. Earth's diurnal rhythms lie deep in the living cells of which our bodies are composed. The lime in our bones and the salt in our blood and tears are the chemicals of Earth's oceans from which our remote ancestors emerged some 400 million years ago. Although we have learned to control our environment (we light the dark, heat the cold, and cool the heat around us) and have come to dominate our planet, we are still as much its creatures as the earthworm turning the soil in the dark or the bright bluejay sounding its raucous challenge from a twig.

When the first Polaris submarines stood out on their two-month, submerged deterrent patrols in the early 1960's, there were no night and no day for their hundred-man crews, only the unchanging artificial light and the steady humming of machinery. It was not long before a drop was noticed in the general efficiency of the carefully selected and highly trained crews. The incidence of poor performance and of inter-personal friction increased as the weeks on patrol wore on. An investigation was conducted and a simple cure was discovered. For eight hours a day when the ships' clocks showed that darkness had come to the surface of the sea, the white lights were turned off and only dim red bulbs illuminated the living spaces of the big subs. The cycle of light

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and dark in which the submariners had evolved for four billion years was restored, and the problem was solved.

In the last 10,000 years we have learned a great deal about our Earth, and what we have learned has changed us from the wandering hunter-gatherers of the Stone Age to what we are today—flawed and imperfect, trailing still the violence and aggression of a million years of the hunt and the kill, but enlightened, curious, reasoning, with much of the old ignorance cleared away and with the potential for creation of a rewarding future out of an ever expanding storehouse of new knowledge.

But if the promise of that future is to be fulfilled, knowledge of the Earth alone will not be enough. A physician cannot gain accurate knowledge of a human body by the study, however thorough, of any one part but must examine the interrelationship of all parts working together. If mankind is to continue to flourish, we must understand the workings of the entire system of which our Earth is an integral part. That system is the Solar System, born of, powered by and having its existence only in relation to its central star, the Sun.

When the first Polaris submarines went on patrol in the early sixties the efficiency of the men like these, seen standing by the missile launching tubes in a drill, lost efficiency because there was no night or day in the subs. Turning off the lights to create an artificial day/night cycle restored efficiency and reduced friction. So closely is Earth and man related to the Sun.

Sir Isaac Newton sometimes called the greatest scientific genius of all time. This painting by Jean-Leon Huens shows the solar system whose laws of gravity and inertia he derived, the prism with which he first divided light into the colors of the spectrum, and the apples whose fall, according to tradition, gave him initial inspiration.

The Long Course of Curiosity

We have been trying to understand the workings of the system, the relationship of the Earth to the Sun, the Moon and the other planets, the place of Earth and man in the environment of space, and the nature of the space environment in which the Earth exists, for a very long time. Thirty-five thousand years ago, in the final period of the Old Stone Age, with the last great ice glaciers covering half his native Europe, a man with a brain and a body like our own took time out from the struggle for survival to record the phases of the Moon by notches cut with flint in a reindeer antler. It is the first known written record of humanity.

In the sixth century B.C., Pythagoras (from the Aegean island of Samos) first determined that the Earth is a sphere, and about a hundred years later, Anaxagoras of Athens, whose stated purpose in life was "the investigation of the Sun, the Moon, and the heavens, "showed that the Moon shines by reflected light and devised a theory of the phases of the Moon. In the second century, Ptolemy in Alexandria, among other accomplishments, laid down rules for predicting eclipses, and tried to understand why the planets (the word is derived from the Greek for "wanderer") moved strangely across the background of fixed stars. He also made the very natural mistake of believing that the Earth is the center of the Universe, with the Sun, Moon, planets and stars revolving around it. It undeniably appears that way. The trouble was that Ptolemy's understandable viewpoint lasted for fifteen hundred years.

In 1543 Nicholas Copernicus published a paper in Poland showing that the Earth and the planets revolve around the Sun, a fact first recognized by Aristarchus of Samos around 280 B.C. but drowned by the comforting Ptolomaic theory and the religious dogma of the Middle Ages.

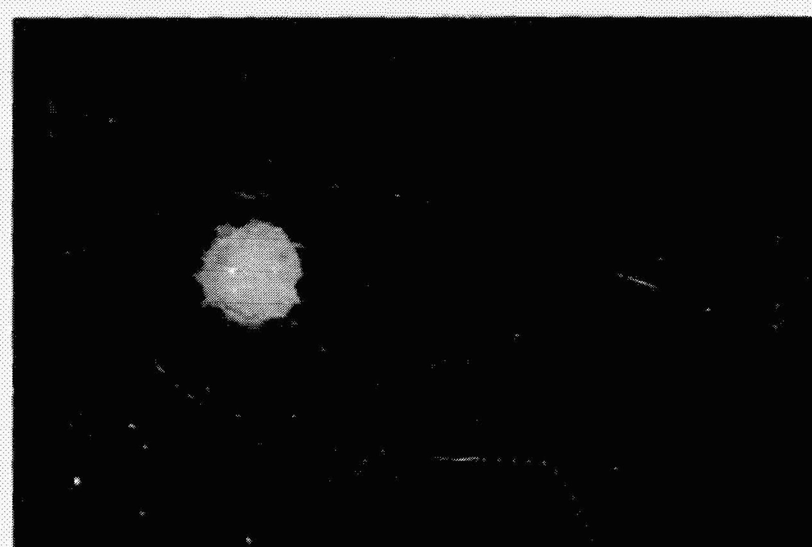
In the early 1600's, Galileo Galilei, working with an astronomical telescope he had developed from a Dutch spyglass, discovered the four largest moons of Jupiter, craters on the Moon, the phases of Venus and confirmed the existence of spots

on the Sun. Later in the same century the German mathematician Johannes Kepler, working with the meticulous, life-long astronomical observations of Tycho Brahe, a Danish nobleman living in Prague, discovered the elliptical nature of planetary orbits and derived the three basic laws which explain and govern their motion. Late in the 17th century, the Englishman Isaac Newton, called by some the greatest scientific genius of all time, derived the laws of gravity and inertia which pervade the Universe and provide mankind with the beginnings of an ability to understand its workings. Newton also handed humanity another key to the understanding of the Universe by first dividing sunlight into its spectrum of colors, thus conceiving the spectroscope, one of the most valuable tools of astronomy.

Two hundred and forty-one years after Newton's death, in December of 1968, when Apollo 8 had rocketed out of its "parking" orbit around the Earth with a six-minute burn of its Saturn IV B stage, and was coasting in a precisely determined trajectory toward man's first rendezvous with the Moon, one of the astronauts, Bill Anders, was patched through Mission Control in Houston to speak to his family at home, including his five year-old son. The boy had only one question:—

"Who was driving?"
Was it his daddy? *No.*
Was it his friend, Colonel Borman? *No.*
Then it must be Captain Lovell. *No.*
Then who *was* driving?
Bill Anders thought a moment, then told his son—"Sir Isaac Newton."
And he was right.

But human interest in the relationship of Earth to the Sun, the Moon and the stars has not been limited to Western Europe. That interest has been global. Curiosity is inherent in *homo sapiens*. If we had not been curious from the beginning we would still be foraging for bugs, berries and small game and nesting in trees at night in fear of the great cats on the jungle floor. Without curiosity we would not have hefted the first throwing-stone, flaked the first flint or stood up straight to peer out over the grass at the edge of the forest. We picked up the first burning



The track of Apollo 8 on man's first orbit of the Moon at Christmas 1968. The flight was planned and executed in accordance with the laws of gravity and inertia derived by Sir Isaac Newton late in the 17th Century. CSM stands for Command Service Module and CM for Command Module.

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branch from a lightening-struck tree and examined it with curiosity, finding it warm, transportable and abhorrent to predators. We pressed the first wild grain seeds into the Earth and covered them to see what would happen and modern civilization was conceived.

All over the Earth, for at least the 35 millennia since the Ice Age lunar observer cut his careful antler notches, men have been curious about the heavens.

In China in 2137 B.C. someone recorded the first solar eclipse, and for a while thereafter eclipse prediction was considered sufficiently important that astronomers were put to death if their predictions were inaccurate.

On the Wiltshire plains of southern England, generation after generation of Bronze Age tribesmen labored for more than 1700 years (2800-1100 B.C.) to build the massive circles and horseshoes of Stonehenge. And "labored" is a seriously misleading understatement. Only part of that epic construction project was the quarrying and transportation of eighty blue stones weighing as much as four tons each, from southern Wales, a straight-line distance of 217 kilometers (135 miles). There is evidence to indicate that Stonehenge was oriented in accordance with observations of the Sun and the Moon and served at least in part as a kind of astronomical observatory.

While Europe was awakening from a thousand years of mysticism and ignorance, the Incas of Peru were observing the summer and winter solstices, when the Sun (in the southern hemisphere) reaches its most southerly and its most northerly points respectively; and the vernal and autumnal equinoxes, when the Sun crosses the equator at the halfway point on its apparent north-south journey, and day and night are of equal length. They also knew not only the dates of the Sun's zenith, when it was directly over their capitol of Cuzco, but the dates of its anti-zenith when it was exactly opposite the zenith point on the other side of the Earth.

Nine hundred years before the coming of the *Conquistadores* in the early sixteenth century, on the Yucatan Peninsula and in what is now Guatamala and Western Honduras, Mayan mathematicians had developed a calendar based on solar, lunar and astronomical observations which was more accurate than the Gregorian calendar of northern Europe, and a mathematics (based on 20 rather than 10 and incorpor-

ating the concept of zero) which was not equalled in Europe for several centuries.

All across North America is scattered the evidence of the deep interest of the early people in the Sun, the Moon and the stars.

Along the eastern slopes of the Rocky mountains where they thrust up through the northern plains is an abundance of circular stone patterns called "medicine wheels." The best known are the Big Horn medicine wheel in Wyoming and the Moose Mountain wheel in southeastern Saskatchewan. Both have spokes aligned to the summer solstice and to the dawn rising of certain bright stars. Carbon-dating shows that the Moose Mountain wheel, 80 meters (90 yards) in diameter, was in use at the time of the birth of Christ.

Outlying cairn and hub of three-century-old Big Horn Medicine Wheel point to the rising Sun at summer solstice. Other cairns align with solstice sunset and the risings of Aldebaran, Rigel and Sirius, indicating the intense interest of the early people of America in the relationship of Earth, Sun and stars.

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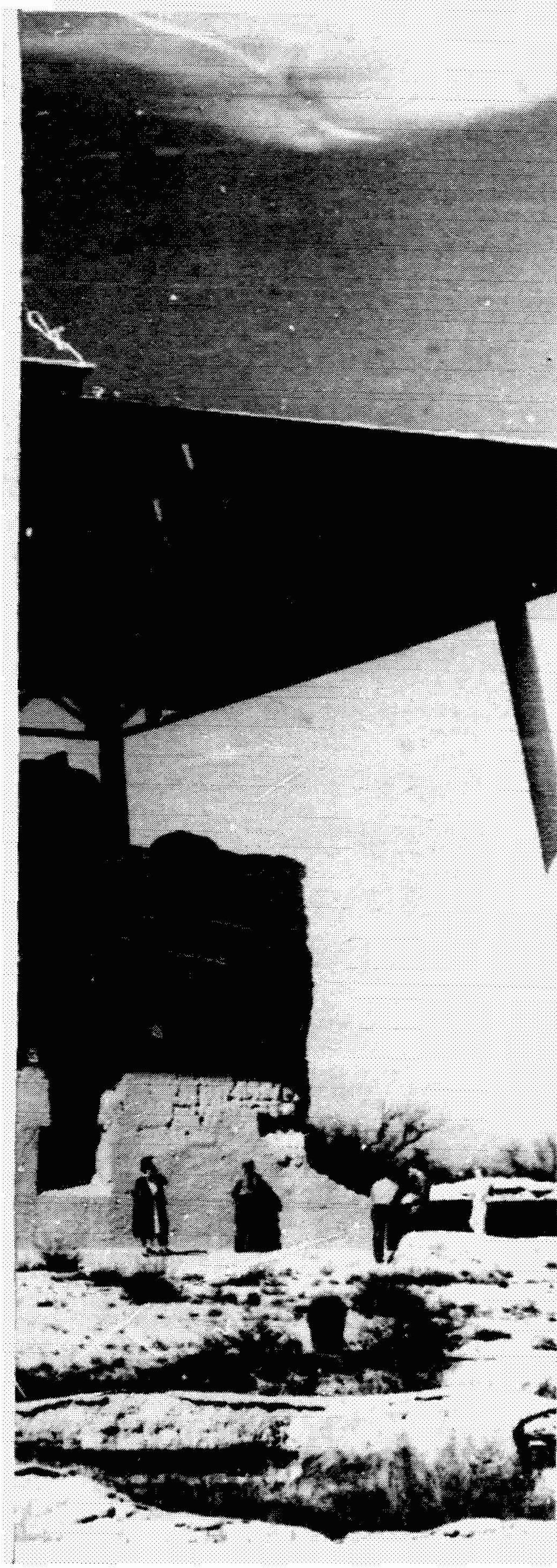
On the top of Fajada Butte in Chaco Canyon, New Mexico, slabs of stone and spiral markings on the rock are so arranged that sunlight coming between the slabs falls upon the spirals to mark high noon of the summer solstice, the winter solstice and the vernal and autumnal equinox.

At Casa Grande, between Phoenix and Tuscon, there is a four-story adobe structure 600 to 800 years old which apparently was used to make complex astronomical observations. One window in the west wall exactly frames the setting Sun at summer solstice. On the east side, two other holes in the four-foot-thick adobe mark the two equinoxes in an elegant and ingenious way. At sunrise around the equinox, light passes through one of the holes, slides as a small, bright spot across a wall, and on that day only, disappears into a small precisely drilled hole in the wall. But the full elegance of the device is marred by the fact that this event now occurs exactly two days *after* equinox. Scientists are trying to determine the reason for the apparent miscalculation. Earth subsidence or ground shifts due to earthquakes or tremors are two possibilities.

Even more intriguing than the novel light and hole arrangement is evidence that the astronomers of Casa Grande had observed and measured a very subtle variation in the Moon's orbit caused by the fact that the plane in which the Moon orbits the Earth is not quite the same as the plane in which the Earth and other planets orbit the Sun (the ecliptic). In fact the



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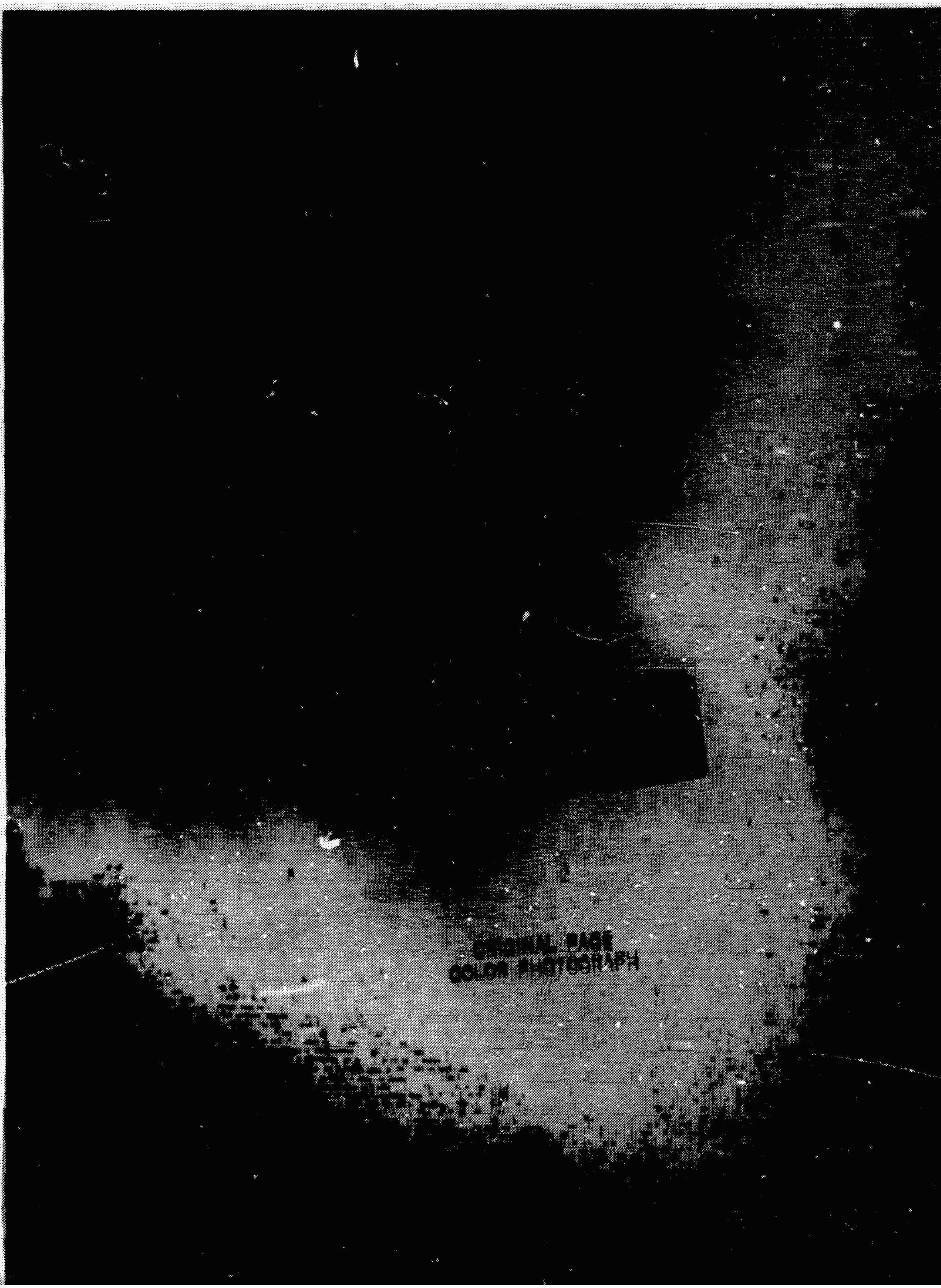
plane of the Moon's orbit is tilted about five degrees to that of the Earth. The effect of this angular difference to an observer on Earth is to vary the Moon's extreme northernmost and the southernmost positions in the sky from a maximum to a minimum in a cycle of exactly 18.61 years. In 1978 the Moon was at its extreme northern and southern points in the cycle. In that year observers at Casa Grande found that at the time of northernmost extreme the Moon was exactly framed in an odd-shaped opening in the northwest wall, and at southernmost extreme by a similar special opening to the southeast.

The message comes clearly across the centuries from the slopes of the Rockies, from Saskatchewan, from the Yucatan, from Cuzco and Chaco Canyon and Casa Grande, from China and Stonehenge—and from other sites in Egypt, India and Cambodia. For 35 millenia, and doubtless for far longer than that, of which no record survives, men have been attempting to discover how Earth and man fit into the scheme of things, attempting to determine their place and function in the Universe, their relationship to the cosmos.

Building on those ancient foundations, we are doing that same thing today. It is just that we have improved our tools.

Casa Grande, between Phoenix and Tuscon used by the Indians of the Southwest for five hundred years to make unusually advanced and complex astronomical observations.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II

THE AGE OF SPACE

This striking view of the solar corona was prepared from data supplied by Solar Max. The colors represent densities of the corona and go from blue (densest) to yellow (least dense). The corona has a temperature of about four million degrees Celsius. The blue, dense coronal regions overlie sunspot regions below on the solar surface.

The accumulation of knowledge accelerated rapidly with the general use of the telescope for astronomical observations in the Seventeenth Century. In Holland, a contemporary of Newton, Christiaan Huygens, an aristocratic intellectual with a wide range of interests, developed the wave theory of light. He held that light in a vacuum behaves like waves in the sea, with similar characteristics of wavelength (the distance between consecutive wavecrests) and frequency (the number of wavecrests which pass a given point each second). His theory is accepted today but with the qualification, derived by Albert Einstein, that light also behaves under certain circumstances like a stream of particles, an idea first conceived by Isaac Newton. Huygens recognized that the Sun is a star and all the stars are other suns, and he believed those other suns had planets just as ours does—a belief generally accepted as fact today although we have not yet been able to observe directly a planet of another star. Huygens also devised a method for measuring the distance to a star by comparing the brightness of the Sun as seen through a small hole in a brass plate with the remembered brightness of the star.

A century and a half after Newton's discovery of the spectrum of light, Joseph von Fraunhofer, a Bavarian optician, incalculably increased the usefulness of that discovery by determining that the number and character of the fine lines he found in the spectrum are precise indicators of the molecules and elements at the light source. Each of the 92 elements which occur on Earth absorbs different frequencies (or colors) of light and displays its own unique and characteristic combination of dark lines in the spectrum. If there is hydrogen at the light source (the Sun, a star, or a cloud of interstellar gas) we see just a few dark lines; if there is iron at the source, we see more than 3000, all at precise locations in the spectrum, each element sending its unique "signature" in the beam of light.

Together Newton and Fraunhofer gave mankind a very useful tool. With it we can determine the chemicals in a star so far away that the light we are seeing in its spectrum left the star before the Earth on which we stand was formed, before our Sun began to shine. With it we can literally experience the past in the present because we are seeing what a star or a galaxy was like when the light we study left it a million or a billion years ago.

And there is more. With this tool, the spectroscope, we can not only determine chemical composition by counting Fraunhofer's lines in Newton's spectrum, but by the character of the lines—dark or shaded, sharp or blurred, shifted toward the blue or the red end of the spectrum—we can read the temperature, density, pressure, strength of gravity, and magnetic and electrical forces at the source of the light.

For a hundred years between the mid-Nineteenth and mid-Twentieth centuries the technologies of the telescope and the spectroscope were advanced and improved. We built bigger and bigger telescopes, culminating in the 200-inch lens on Palomar mountain in California. Out of the spec-

troscope was derived the spectroheliograph for the more careful scrutiny of the Sun in selected single lines of color, each of which occurs in the Sun at different temperatures and therefore at different levels in the Sun's atmosphere. With the coming of the camera we increasingly substituted high sensitivity film for the human eye. In the late 1930's we began to scan the skies with radio telescopes, observing for the first time in a part of the electromagnetic spectrum other than the relatively narrow band of light our eyes can see.

Each of these improved technologies, as they became available, were applied to solar research, and by the time humanity was hurled willy-nilly into the Space Age with the purposeful overhead beeps of Sputnik (in the autumn of 1957), we knew a lot about our sample star.

Knowledge of the Sun in 1957

We knew its distance from the Earth—a mean of 150 million kilometers or 93 million miles, a distance we call an Astronomical Unit, or AU, and use to describe gross measurements within the solar system.

We knew its age—the same as that of Earth, about 4.6 billion years. And we knew its life expectancy—about five billion more years.

We knew its size—1,390,000 kilometers or 864,000 miles in diameter with a volume 1,300,000 times that of the Earth and a mass (a quantity of matter) 330,000 times that of our planet.

We knew its chemical composition—about 80 percent hydrogen, 19 percent helium and trace amounts of about 70 of the other 90 elements which occur on Earth.

We knew its general structure—a huge, spherical nuclear furnace enclosed by the bright surface which we see, the photosphere, and above that two tenuous layers called the chromosphere and the corona, separated by an ultra-thin band of space called the transition zone. And we knew that the Sun maintained its structure, shape and size by means of a dynamic balance between outward pressure from the heat of the nuclear reaction and inward pressure from the mass of material surrounding it.

We knew its temperatures—about 5000 degrees Celsius (9,000 degrees Fahrenheit) in the photosphere, from 4000 to 500,000 degrees Celsius (7000 to 900,000 degrees Fahrenheit) in the chromosphere, a half million to three million degrees Celsius (900,000 to 5,400,000 degrees Fahrenheit) in the corona, and sixteen million degrees Celsius (29,000,000 degrees Fahrenheit) at the center. For comparison, the temperature in the gas burner of a kitchen stove is 1000 degrees Fahrenheit and in the hottest furnace used for the production of steel, it is 10,000 degrees Fahrenheit. Sir James Jeans in his famous book, *The Universe Around Us*, calculates that the heat from a pinhead-size piece of material from the interior of the Sun would kill a man a hundred miles away.

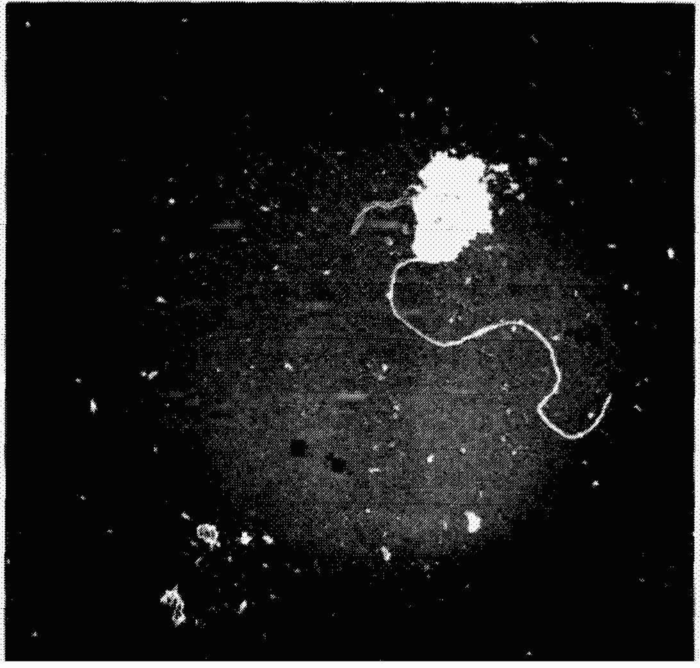
When the Space Age dawned we also knew, or were reasonably certain we knew in a general way, the process which powers the Sun and makes it shine and radiate energy—atomic energy in the form of thermonuclear fusion. This is the same process which powers the other stars—and the hydrogen bomb. In the nearly

immeasurable temperatures and pressures of the Sun's interior (29 million degrees Celsius and a trillion pounds per square inch) hydrogen atoms, which have one electron circling a nucleus of one proton, are driven together in high speed collisions and fused into helium atoms with two electrons and two protons, thus converting hydrogen into helium and releasing huge amounts of energy in the process.

The explosion of a ten-megaton hydrogen bomb effectively converts about one pound of matter into energy. The Sun converts about five million tons of matter into energy each second.

By 1957 we also knew that the Sun rotates unevenly, because it is not a solid with a molten core like the Earth, but a ball of flaming gas, with points on the equator rotating around the axis every twenty-five days, points at the poles about every thirty-three days and areas in between rotating at intermediate rates.

Sunspots as seen through an ordinary telescope. Sunspots are indicators of solar activity, varying from minimum to maximum every 11 years.



We had also long known about sunspots as well—cooler areas associated with strong magnetic fields, which show darker than their hotter surroundings and which come and go, increasing and decreasing in size and number, in cycles of eleven years.

Finally we "knew" that, although quiet and burning with benign steadiness most of the time, the Sun occasionally flares and fires streams of energetic particles across the solar system some of which penetrate and react with the atmosphere of Earth.

By the late 1950's large amounts of valuable knowledge concerning the nature of the immediate environment of the Earth had been added to the human storehouse.

We knew, and had known even before Prince Henry's navigators began using the magnetic compass, that the Earth was a planetary magnet with north and south magnetic poles which do not coincide with the geographic poles.

We knew the composition of the atmosphere—at its lower levels 78 percent nitrogen, 21 percent oxygen, one percent argon, and lesser amounts of carbon dioxide and other gases.

We knew the atmosphere was structured, with a troposphere, in which most of our weather occurs and within which the temperature generally decreases with altitude, extending from the surface to 10 miles above; a stratosphere from about 10 to about 45 miles in which the temperature remains essentially constant; and an electrically charged ionosphere, with three regions of its own, extending from the top of the stratosphere out to about 600 miles.

We had not known about the ionosphere for very long in 1957. Its existence had been discovered independently in the early decades of this century by an English physicist, Oliver Heaviside, and an American electrical engineer, Arthur Kennelly. Their discovery of the ionosphere was one

National Geographic Society, 1965

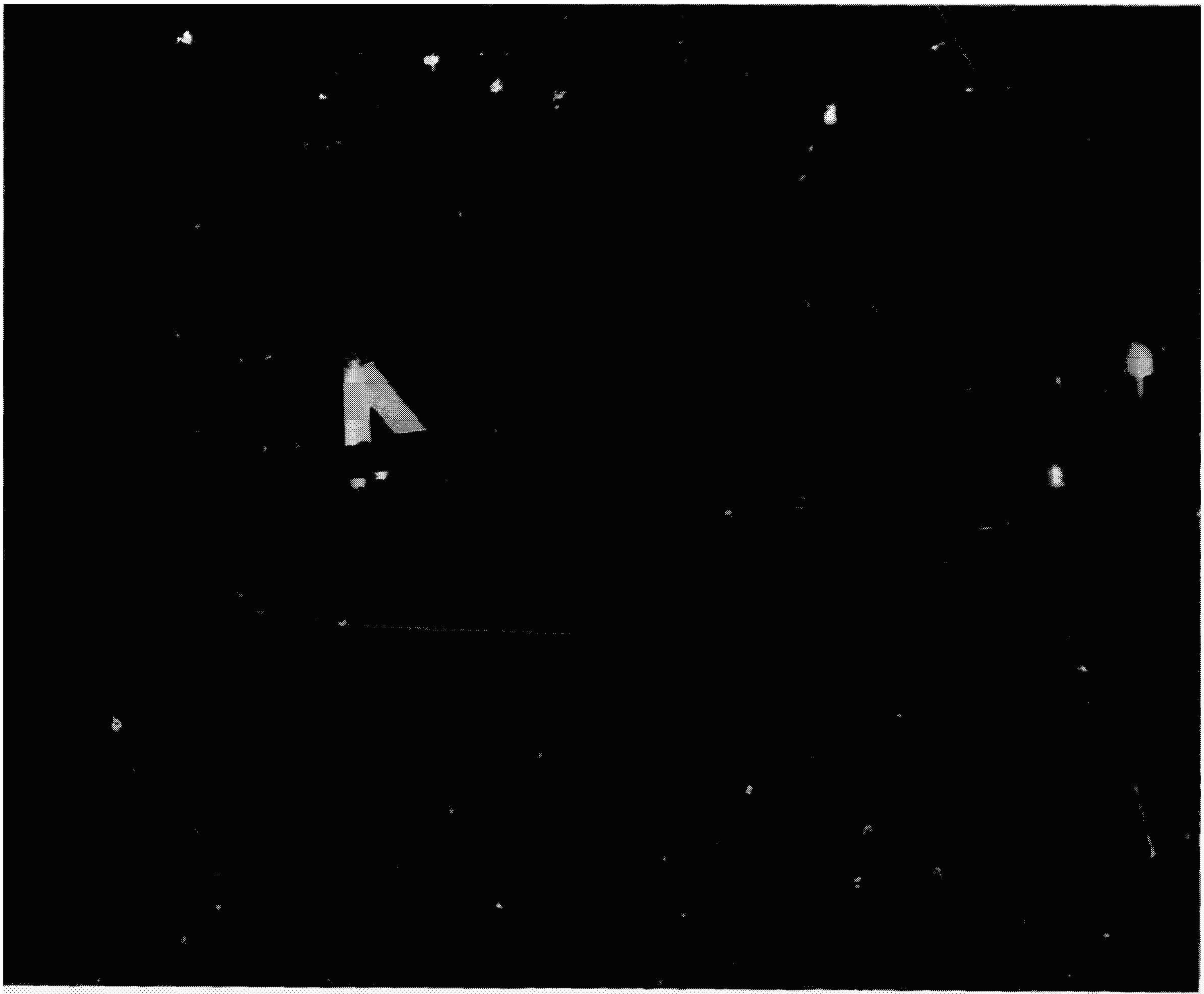
This is what we knew about the Sun, its radiation, the atmosphere of Earth and the penetration of atmosphere by solar radiation when the Age of Space began.

of our era's noteworthy additions to human knowledge. It is the ionosphere which acts as a protective screen around the Earth, allowing the Sun's light and warmth to reach the surface but absorbing the lethal wavelengths of ultra-violet rays (some of which get through to cause Sun tan and skin cancer), x-rays and gamma rays.

It is also the ionosphere which makes long distance radio communications possible by reflecting back to Earth low, medium and high frequency radio waves, while letting the very high frequencies, including those of TV, pass out into space to provide only line-of-sight, or short range communications.

When Sputnik was launched into its first beeping loop around the planet, we had a basic working knowledge of the Sun and of the Earth's immediate environment in space. But we were like the physician who has a good knowledge of the brain and of the hand but knows very little about the relationship between them. Certain relationships had always been obvious—night and day, the change of seasons, the need of all living things for sunlight—but the mechanism, the cause-and-effect relationships between the Sun and Earth, the interactions between solar phenomena and the Earth's environment and the effects of those interactions were largely unknown.

One of the reasons for our relative ignorance was that from the dawn of human interest in the subject we had been working with a built-in disadvantage. That of

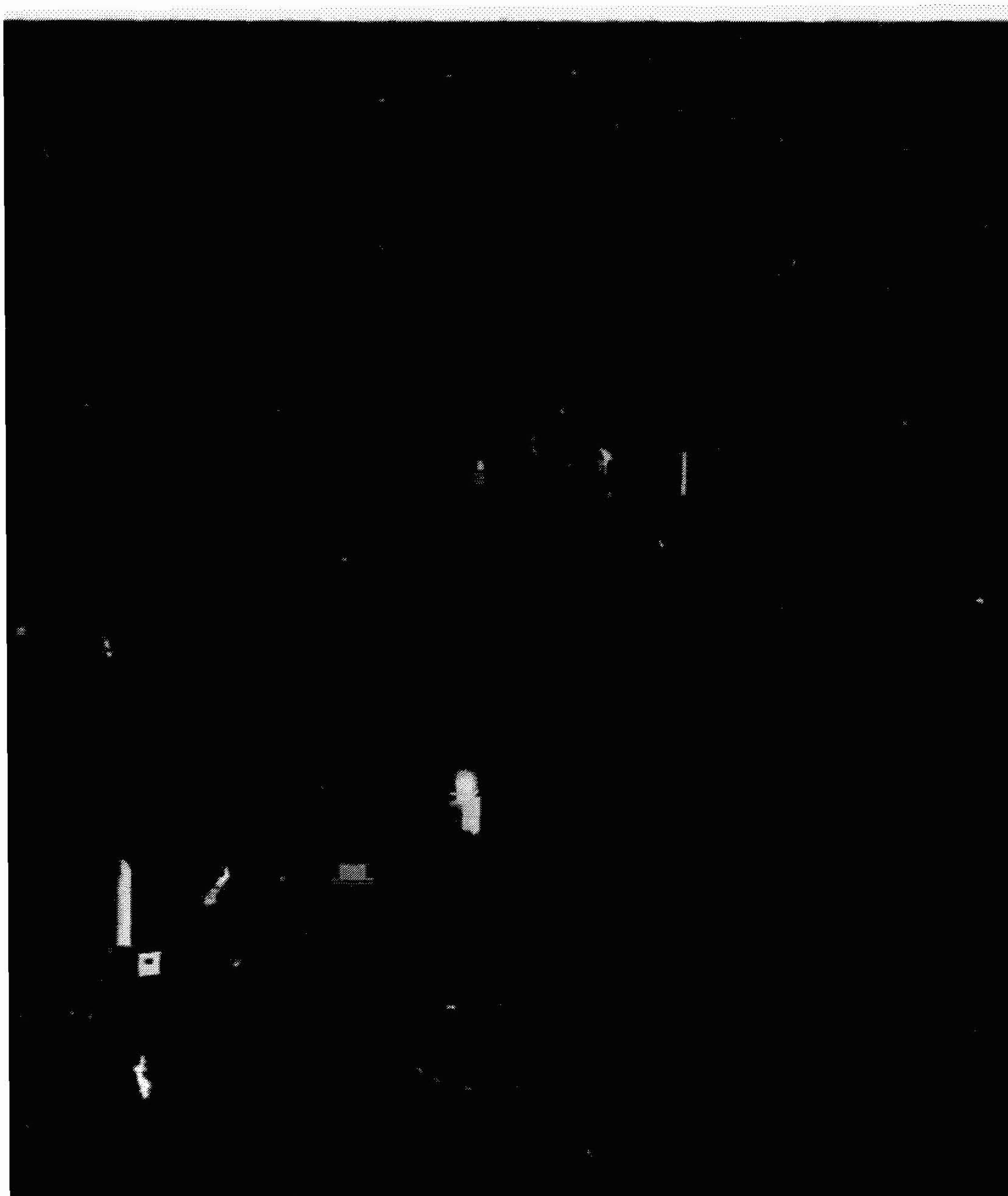


advantage was the dichotomous effect of the Earth's atmosphere. The air we breathe and need to live, the atmosphere which shields us from the lethal emissions of the Sun and the cosmos, at the same time effectively prevents us from studying those emissions and interposes a shimmering, translucent veil be ween our observing instruments and the Universe. The frustrations of this scientific fact have given rise to a standing joke within the scientific community. When good astronomers die they go to the airless Moon from which they can observe the heavens, unhindered through eternity.

In an attempt to overcome that disadvantage, we had built our astronomical observatories on moutain tops in desert regions to position them as close to the surface of the ocean of obscuring air as possible and far away from man-made pollutants. We had sent telescopes and instruments in balloons into the stratosphere. Beginning in 1946, we had mounted instrument packages in the noses of war-developed rockets and fired them high above the Earth where for a few moments they could obtain unobscured glimpses into the Universe.

The Dawn of the Space Age

With access to space a whole new array of powerful and effective tools became available to mankind in our quest for an understanding of the nature of our space environment and especially of the vital relationship between our planet and its star.



National Geographic Society, 1965

Kitt Peak National Observatory in the Quinlan Mountains 56 miles west of Tuscon, Arizona. The location was chosen for its altitude which is above much of the obscuring atmosphere, and for its remoteness from sources of man-made atmospheric pollutants.

The ability to observe from outside Earth's atmosphere, directly by being there in person or remotely with automated instruments, enables us for the first time to examine the Sun and the Universe in a systematic way in all the wavelengths and frequencies of the electromagnetic spectrum. Dr. Herbert Friedman of the Naval Research Laboratory has suggested the analogy of the piano as a convenient device to understand the electromagnetic spectrum. Just as the notes on a piano differ from their neighbors in frequency—the rate at which their strings vibrate—and cause more or fewer wavecrests of sound to impinge on the ear each second, so do the vibrations in the electromagnetic spectrum. At the low end of the spectrum, comparable to the bass notes on the piano, are radio waves with distance between wavecrests (wavelength) measured in meters, centimeters and micrometers (millionths of a meter). At the other end, comparable to high notes, are gamma rays and x-rays with wavelenghs measured in angstroms (one hundred millionths of a centimeter). Somewhere near the center, in the vicinity of middle C, is the narrow band of visible light which Newton divided into colors with his prism, with red light at the low frequency end and violet light on the high frequency side. The wavelengths of visible light are measured in thousands of angstroms, 4000 for violet, 7000 for red.

The early years of the Space Age were exciting for scientists, especially for astronomers, astrophysicists, solar physicists and those in related fields. For them access to space was like the lifting of a veil between their instruments and the Universe.

With the ability to observe all across the spectrum, knowledge poured in from constantly improving instruments, first in near-Earth space and later from instrumented probes spinning inquisitively through the solar system. Every spacecraft put up sent back new and revealing data, often entirely incidental to the mission for which it was designed and intended. America's first orbiting spacecraft, the 30-pound Explorer I, launched four months after Sputnik, was designed to map the Earth's distant magnetic field. Explorer I was to do this by mapping the energies of incoming particles that succeeded in penetrating to different parts of our outer atmosphere and by observing the boundary between the flood of incoming particles from space and the Earth's atmosphere. But, it provided no useful data on that subject and was therefore, technically, a failure. However, what it did do, by means of simple radiation counters, was to discover that there were very energetic, charged particles trapped in bands around the Earth far above the upper atmosphere—the now familiar Van Allen radiation belts.

We learned a valuable early lesson from the technical failure but incidental success of Explorer I. We learned that out on the frontiers of scientific research and experimentation, as on the physical frontiers of Earth, the key to success is flexibility and versatility, a readiness to find and exploit the unexpected. To be rigid or legalistic is to invite failure, not technical but actual. Just as, rigidly interpreted, the explorations of Christopher Columbus were failures because the mission for which they were designed, the charting of a westward passage to the Orient, was not accomplished.

Recipe for Research

With the establishment, in 1958 of the National Aeronautics and Space Administration, a blueprint was developed for the orderly and progressive accumulation of knowledge concerning Sun-Earth relationships utilizing our newly acquired access to space. The blueprint called for a phased, step-by-step progression, which still guides U.S. plans and policies for space research.

The first phase is *exploratory*—the initial gathering of data and the taking of measurements for the first time. This is the stage of Explorer I and the early years of the Space Age when everything we learned was new, valuable and exciting. It is the first voyages of Columbus, with new lands discovered every week. Most of the spacecraft used in this phase are "Explorers" or "Pioneers."

The second phase is that of *survey*, when the measurements and data from exploration are given shape, dimension, extent. In the process of surveying it is probable that new discoveries will also be made, so that there is an overlap between exploration and survey, as between all the phases of the blueprint. In this phase Columbus, having discovered the new lands to the west, began to map and chart them. Indeed, some of the spacecraft used in this phase are called "Surveyors."

The third phase could be called *explanatory*. The attempt to understand phenomena, function, mechanisms and effects, of course, takes place during all the phases but at this stage, with most of the pieces of the puzzle in hand, the effort is to fill in the gaps, to determine specifically what we need to know to understand, and to acquire that information. Often, for example, simultaneous and identical measurements must be made at

widely separated locations, or the same measurements made at the same locations at different times, based on data provided by previous surveys.

The final phase is the *application*, or exploitation, of the knowledge gained. When we have determined the extent of the Earth's magnetic field we know how and where to send our spacecraft to locate and measure the magnetic fields of other planets. What we learn about our Sun helps us in our study of other stars, provides a guide which tells us what to look for, what to expect. We apply our new knowledge to place weather and communications satellites in their most effective orbits, to provide advance warning of geophysical disturbances, and to begin to learn how to harness the power of the Sun for generating electrical power.

Early Efforts and Discoveries

The blueprint for research began to unfold in 1958 and information began to flow back to Earth from a variety of increasingly capable space vehicles and instruments.

But reliable access to space was not achieved instantaneously. In those early years, the launching process was a high-stakes gamble, with tens of millions of dollars at risk. In the blockhouses at Cape Canaveral and later at Vandenburg Air Force Base in California and Wallops Island on Virginia's Eastern Shore, men held their breaths and prayed as the countdowns reached zero and the rockets with their delicate and expensive instruments were aborted. Nor did a good launch assure the success of a mission. Each of the rockets' several stages had to burn out and ignite in precise succession if the payload were to enter the proper orbit—or any orbit at all. The guidance systems had to function perfectly or the Range Safety Officer was obliged to destroy the launch vehicle to avoid impact in Titusville, Merritt Island, or Cocoa Beach. And once in orbit, the spacecraft instruments had to function as planned, despite the high acceleration forces, the vibrations and the air-friction temperatures of the trip to orbit.

In 1958, the United States attempted 19 launches. The score: 11 successes, 8 failures. The following year it was 16 and 13, and in 1961 it was better: 29 to 12. Nevertheless, it was another dozen years before a perfect score was achieved: 30 for 30 in 1972.

But the risks were accepted, the scores steadily improved, the losses were cut, the successes mounted, and mankind's store of knowledge increased at an accelerating rate.

Explorer I was followed by no fewer than 49 spacecraft between 1958 and the present. They explored and measured the ionosphere, confirmed the existence of a layer of neutral helium atoms in the upper atmosphere; detected solar magnetic influences near Earth; completed a detailed study of space between the Earth and the Moon (cislunar space) with special attention to solar and cosmic particles and magnetic fields; monitored the x-ray and ultraviolet emissions of the Sun; investigated the density, radiation characteristics and other phenomena in the Earth's upper atmosphere at times of both high and low solar activity; studied the dynamics of magnetic storms and auroral displays; measured the number, size and penetrating ability of micrometeroids in space; monitored the Sun's radio noise; and examined the processes by which the Earth's

atmosphere absorbs the Sun's potentially lethal ultraviolet rays.

Perhaps the single most significant discovery made collectively by the Explorers was the existence and general characteristics of a fluctuating, elastic, protective shell of magnetic force which encloses the Earth and (although it is not spherical at all) is called the magnetosphere. The discovery of the magnetosphere followed closely on another comparably significant and closely related revelation—the existence of a *continuous* flow of hot, charged particles from the Sun, called the solar wind, which pervades the solar system. The existence of the solar wind was confirmed by particle detectors on Pioneer 5, coasting silently between Earth and Venus in 1960, and came as a surprise to most scientists.* Only a half a decade before, we "knew" that the Sun was quiet most of the time and only occasionally threw off streams of particles.

The enlightening and somewhat humbling discovery of the solar wind with its major but yet to be understood role in the dynamics of the solar system, reconfirms the intuitive genius of the American humorist Josh Billings who wrote "T'ain't what we don't know, but what we know that ain't so, that hurts us."

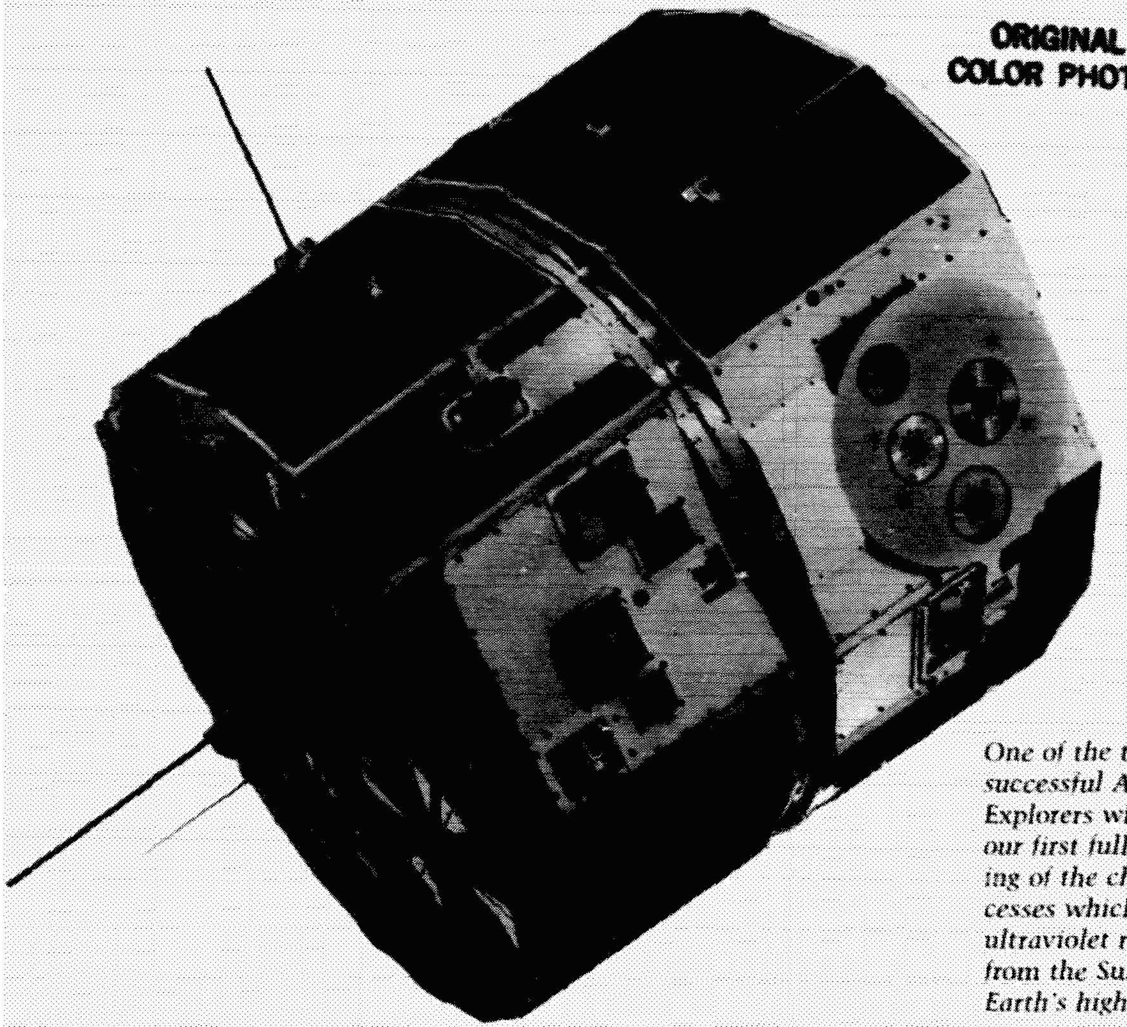
The existence of the solar wind and the magnetosphere provides a radically new concept of the Earth and its environment. We now see our planet as a blue and white ball enveloped in the invisible sheath of its magnetosphere plowing around the Sun through the equally invisible streaming particles of the solar wind. There appears to be a rather sharp and abrupt boundary (the magnetopause) between the Earth's magnetic field and everything beyond it. Generally speaking, everything inside is part of Earth-space and moves with it, everything outside pertains to the Sun or the Cosmos.

The Explorers

The Explorers and other spacecraft have shown that the passage of the Earth through the solar wind as it circles the Sun has shaped the magnetosphere somewhat like a celestial tadpole, the pressure of the solar particles pressing it close to the leading or upwind edge of the Earth and stretching its tail far out into the wake astern. As a blunt-bowed barge being pushed upstream creates a hump of moving water ahead; as an eighteen-wheeler barreling down the highway pushes a wave of air that rattles approaching cars and forces passing ones away, or as an aircraft flying at supersonic speeds creates a shock wave of air that we hear as a sonic boom, so does the Earth's magnetosphere create a bow or shock wave where it meets the pressure of the solar wind. Thus the magnetosphere extends out only about ten Earth radii (64,000 kilometers or 40,000 miles) toward the Sun, but is stretched out hundreds of times farther down-Sun like the tail of a comet.

The Explorers also found that inside the magnetosphere, including its extended tail, (the magnetotail) large amounts of energy are stored and flow generally along the force lines of the Earth's magnetic field. Explorer instruments showed that

*Some had deduced its existence by observing the tails of comets which always stream away from the Sun whether the comet is approaching or receding. Pioneer 5 also made the first measurements from space of the nature of solar flares.



One of the three highly successful Atmosphere Explorers which gave us our first full understanding of the chemical processes which occur when ultraviolet radiation from the Sun strikes the Earth's high atmosphere.

this energy is derived from the solar wind by a process we still don't fully understand.

In the early to mid-1970's a series of three Explorers were especially designed and flown to make detailed studies of the Earth's high atmosphere and its interactions with solar radiation. These spacecraft, the Atmosphere Explorers, were significant not only for the value of the data they returned but for the advance they represented in the way that data was selected, obtained, distributed and used. The three Atmosphere Explorers were the first such tools to exploit the concept of correlative or interdisciplinary research by which satellites are instrumented and used by a team of scientists working closely together to investigate a broad range of aspects of the same problem. The Atmosphere Explorers studied the ionosphere, for example, not in isolation but by acquiring and correlating information on the Sun's ultraviolet radiation, on cosmic rays and other "background" emissions from the galaxy, and on the end products resulting from the interaction of both with the high atmosphere of Earth. And in another departure from custom, the information they obtained was fed into an on-line data system where it was immediately available to all members of the scientific team, wherever located, by means of convenient and relatively inexpensive computer terminals.

The Atmosphere Explorers provided a major milestone in our progress toward an understanding of the chemical processes which occur when ultraviolet radiation from the Sun strikes the Earth's high atmosphere. Current theories about those processes were re-evaluated and corrected and formed the basis for further research.

The Pioneers

While the Explorers were investigating the nature of near-Earth space, a series of eleven Pioneers, ranging farther afield, began a reconnaissance of the solar system including the Sun, the other planets, and the chemistry and physics of the space between them. Paralleling the procedures established for the study of Sun-Earth relationships, planetary exploration had its own blueprint. It called for three phases: *reconnaissance*, consisting of close "fly-bys" and photography (actually "imaging" without the use of film); *exploration*, involving the use of orbiters and probes to map and measure; and *intensive study*, using landers for close-up detailed examinations.

But the Pioneers, although all but four were primarily designed for planetary exploration, also carried instruments, such as those on Pioneer 5 that confirmed the solar wind, for measuring the interplanetary medium. Thus measurements by the distant Pioneers could be and were coordinated with similar measurements by the Explorers to provide a variety of puzzle pieces for eventual integration into an improved over-all understanding.

Pioneers 6 through 9, launched from late 1965 to late 1968 into orbits around the Sun both slightly inside and slightly outside that of Earth, acted as long-term monitors of the Sun's emissions from widely separated points and over long periods in the solar cycle. Pioneers 10 and 11, launched a year apart in 1972 and 1973 to fly by and reconnoiter Jupiter and Saturn, made and are still making similar measurements from hundreds of millions of kilometers away as they approach the orbits of the outer planets. Pioneer 10, sometime in 1986, will cross the mean orbit of Pluto and become the first man-made object to leave the solar system. Pioneer 11 will follow in 1994 but in the opposite direction. It is possible that the power supply, instrumentation and stabilization of Pioneer 10 will survive long enough to locate the limits of solar radiation, to define the distant boundary where the Sun's dominion ends and the empty darkness of the galaxy begins.

A series of enormous storms on the Sun in early August of 1972 showed how well the Pioneers could work together to add to our knowledge of solar phenomena. When the storms broke, Pioneers 6, 7, 8 and 9 were in orbit around the Sun at a distance of about one AU, with Pioneer 9 closest to Earth. Pioneer 10 was some 214

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Relative positions of Sun, Earth and the Pioneers at the time of solar storms of August 1972.

Artist's concept of Pioneer 10 or 11 approaching giant Jupiter. The objects at the ends of the two booms are the radiative thermal generators which provide electrical power. The large dish antenna is pointing back toward Earth.

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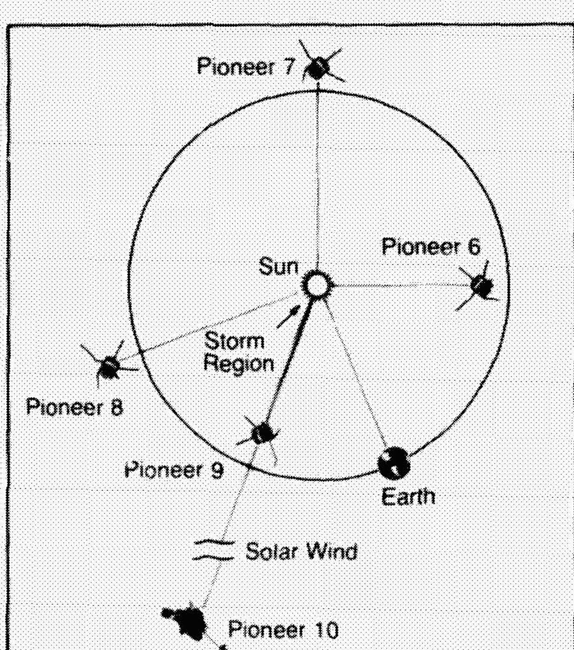
million kilometers (133 million miles) from Earth, deep in the asteroid belt, on its way to Jupiter and Saturn. The four Pioneers circling the Sun measured the solar wind and magnetic fields from the storms as they swept out through space, with Pioneer 9 recording the highest solar wind speeds ever measured, about 3.6 million kilometers per hour (2.2 million miles per hour). Three days (76 hours) later, when the blast of solar wind hit Pioneer 10, the spacecraft's instruments found that the solar wind had lost about half its velocity but that its temperature was about the same as that of the solar corona where it had originated, about 2 million degrees.

Another pair of planetary explorers, the Voyagers, with more advanced instruments and greatly increased capabilities, are following the trail broken by Pioneers 10 and 11. The Voyagers also are measuring the qualities of the solar wind as they too head for the remotest of the planets and out into the void between the stars. Voyager I will cross Pluto's orbit in 1989,



Voyager 2 in 1992. It may be one of them, or both, which finally define the heliosphere.

When the Pioneers and Voyagers leave the solar system they will be beginning an odyssey through space which in all probability will outlast the existence of Earth and man. Although their departure speed will be more than 13.6 kilometers per second, or roughly 30,000 miles per hours, so vast are intra-galactic distances that at the end of 40,000 years they will have flown just half the distance to the nearest star.

Orbiting Solar Observatories

Still another series of spacecraft, entirely different in design and purpose, has also served to increase our understanding of the Sun in the exploratory phase of our learning process. These are the Orbiting Solar Observatories or OSOs, the first of which was launched in the spring of 1962.

There were eight of these observatories, with the last, OSO-8, launched in the summer of '75. Whereas, the Explorers were generally designed to acquire a broad range of data, the OSO's zeroed in to study specific details, physical processes, and areas of the Sun in high resolution. The OSOs have kept their instruments trained on the Sun from 1962 to 1978, about one and one-third of the Sun's 11-year solar cycles. They have returned valuable data on solar flares, on the nature of the corona, on solar activity in the gamma ray, x-ray and ultra-violet bands of the spectrum, and increased our understanding of the Sun's constitution and behavior.

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Skylab

The next step in man's study of the Sun was truly a giant leap. It was the world's first, full-scale, manned, orbital astronomical observatory, bigger than a boxcar, equipped not with the miniature versions required by the size and weight limitations of the OSOs, but with full-size, first class observatory instruments and with its observations and investigations planned, directed, supervised and coordinated by the entire international community of solar scientists. This first American space station and scientific workshop was Skylab.

Skylab weighed about 91,000 kilograms (100 tons), was 36 meters (118 feet) long and some 6.7 meters (22 feet) in diameter, and contained the most complex and varied assortment of scientific instruments and equipment ever to leave the atmosphere of Earth. It took the Saturn V rocket which launched the Moon missions to lift Skylab to its orbit 435 kilometers (270 miles) above the Earth. But when it arrived there on May 14, 1973, it was useless and uninhabitable, without electricity to power its systems and with its interior temperature about that of a medium oven. Enroute to orbit, one of its two main solar panels designed to provide electrical power had been ripped off and the other jammed uselessly in the folded position. In addition, the Sun shield required to maintain the interior at liveable temperatures had also been torn away.

There was real danger that eight years of planning and a billion dollars would be irrevocably lost.

The starship-like console which controlled the eight instruments of Skylab's Apollo Telescope Mount. Scientist-astronaut Edward G. Gibson of the final Skylab crew is at the controls.

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A huge solar eruption photographed by one of the Apollo Telescope Mount instruments in Skylab. Its size can be judged by the small white dot at upper left which represents the size of the Earth.

But on May 25th, in a display of calm competence, engineering ingenuity and just plain physical courage, astronauts Pete Conrad and Joe Kerwin climbed aboard the orbiting derelict to make repairs. Using special equipment imaginatively and quickly designed and fabricated by NASA engineers on the ground in Houston, they successfully freed the fouled solar panel, rigged a substitute Sun shield, powered up their orbital laboratory and went to work.

In the following nine months, in much the same manner that the Apollo explorations revolutionized our knowledge of the Moon, Skylab "rewrote the book" about the Sun.

The tools used were an assemblage of eight solar instruments known collectively as the Apollo Telescope Mount, or ATM. In the ATM, two x-ray telescopes examined and photographed the low and intermediate portions of the Sun's corona. Three ultraviolet instruments studied the chromosphere (the "color sphere," a thin layer below the corona which, with the corona, makes up the Sun's outer atmosphere). Two Hydrogen-Alpha telescopes provided target identification, pointing and reference, and by using an attached 35 mm camera kept a continuous record of solar conditions and ATM pointing. Finally a white light coronograph took high-resolution photographs of the corona in visible light. Each of these instruments was the most advanced of its type ever flown in space.

This entire battery of instruments could be pointed with a precision which could define the width of a dime at a distance of a mile and a quarter.

Skylab as seen by the last crew before returning to Earth on February 8, 1974. The Apollo Telescope Mount is at the hub of the four narrow panels and above the improvised Sun shield which saved the mission. The left main solar panel is missing.

One of the major advantages of Skylab was that because it was operated by human crews who eventually returned to Earth, its observations could be recorded on film rather than transmitted in millions of "bits" by radio. In 3900 orbits in 171 days of manned operations, more than 150,000 observations were recorded on film and brought back by the returning astronauts. It should be noted here that improvements in imaging technology since Skylab have reduced the relative advantage of using film, as witness the vivid and informative pictures returned by the Voyager spacecraft.

The Skylab crews worked closely and continuously with scientists and observatories on the ground, exchanging data, occasionally alerting one another to budding solar phenomena, consulting and advising. Skylab proved not only that man could live and work competently for long periods in space (the third crew stayed for 84 days) but demonstrated the versatility and flexibility provided by the human presence. Skylab astronauts not only saved the entire project, they reloaded film packs in spacewalks outside the station, repaired and replaced cameras, freed jammed filter wheels, re-opened external doors that failed in the closed position blinding instruments, replaced television tubes and modified equipment to improve performance.

The Americans of Skylab saw the Sun as no human beings had ever seen it before, and the mass of knowledge they acquired, although quickly and thoroughly disseminated, has hardly begun to be used.

Because of Skylab we have a new understanding of the complex and important relationships between the various layers of the Sun's atmosphere.

Skylab's instruments examined coronal holes first reported by the OSOs and impossible to view from Earth, which may prove to be of more significance to our

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planet and its inhabitants than any other solar phenomenon as sources of high-speed jets of solar wind. The later observation of one such jet illustrates the effectiveness of scientific teamwork for the acquisition of knowledge.

In late January of 1974, Explorer 47 (also designated Interplanetary Monitoring Platform 8 or IMP-8) detected and measured from far out in space a high-speed stream of solar wind originating from a coronal hole observed and photographed by the last Skylab crew in low Earth orbit. Alerted by IMP-8 and Skylab, scientists on the ground at NASA's Joint Observatory for Cometary Research recorded distortions in the tail of Comet Kohoutek as the solar wind stream swept across it. Four days later, as the rotation of the Sun aimed the coronal hole at Earth like the nozzle of a garden hose, the solar wind stream collided with Earth's magnetosphere, and ground-based instruments recorded a strong geomagnetic storm.

Perhaps most spectacularly, Skylab discovered the coronal transient—colossal bubbles of coronal material bigger than the Sun itself which blast out periodically across the solar system at millions of miles an hour.

Skylab was the most intensive effort in all of history to increase man's knowledge of the Sun. It rewrote the book on solar physics and that rewriting will go on for years. It has been estimated that more than three-quarters of all the active solar physicists in the United States (to say nothing of those of other nations) have been or will be involved in some aspect of Skylab's observations. But perhaps as important as the new knowledge it brought us is the knowledge which it showed us we need. And shortly after the last Skylab crews had splashed down in the Pacific we moved to seek that knowledge and the age-old effort to understand continued.

A giant prominence erupts from the Sun and is caught by Skylab's cameras. Temperatures in the huge loop vary between 20,000 and 70,000 degrees. Its closed shape show evidence of strong magnetic lines of force.

Helios

Manned operations from Skylab ended early in February of 1974. In early December the next major effort to unlock the secrets of the Sun began with the launching of the first part of a two-spacecraft mission called Helios.

Helios is a joint U.S-West German project approved by President Johnson and Chancellor Erhard in November of 1966. Under the terms of the agreement Germany provided the spacecraft themselves and seven of the 10 on-board scientific instruments. The United States provided the launching rocket, launched the spacecraft, maneuvered them into their designated orbits around the Sun, tracked them by means of NASA's Deep Space network and provided three scientific instruments. Generally speaking the United States put the German spacecraft where they were supposed to be and then turned them over to German control. Each country analyzed the data from its own instruments. The second Helios was launched 13 months after the first, in mid-January, 1976.

The scientific purpose of Helios is to study the composition, density and dynamics of the solar wind, space plasma (ionized or electrically charged gases) the magnetic and electrical fields, cosmic rays and cosmic dust, closer to the Sun than human instruments had ever gone before. Both carry instruments which can differentiate between plasma particles which originate in the Sun and those which come from the galaxy. At the closest points in their orbits about the Sun (perihelion) they approach to within about three tenths of the distance from Sun to Earth (.3 AU) or about 43 million kilometers (26 million miles).

Although the two spacecraft approach almost equally close, they are widely separated in space, usually on opposite sides of the Sun. With Pioneers 6-9 at one AU, Explorers 47 and 50 looping around the Earth in orbits which take them far out into space and then back to graze our atmosphere, and with Pioneers 10 and 11 and Voyagers 1 and 2 sailing past the outer planets, Helios forms part of a battery of instruments which give us simultaneous measurements of the same phenomena from the heart of the solar system to its frozen outer fringes. From such measurements we know that at .3 AU the solar wind is relatively dense and structured; whereas Pioneer 10 has told us that at 24 AU it is thin and disorganized, demonstrating an attenuation over the billions of kilometers between, and the probability of an eventual limit beyond which it yields to the interstellar medium.

With its instruments three times as close, Helios has even been able to improve on the understanding of the Sun's corona that we acquired from Skylab.

Readings from Helios have also provided scientific surprises. They show that at one-third the distance from Sun to Earth there are four times as many micrometeroids in space than at the distance of Earth's orbit, and that their chemical composition differs, showing that they come from different sources. Another surprise was that the flux, or rate of flow, of the particles in the solar wind is 15 times higher at .3 AU than at 1 AU, a much greater increase than was expected.

International Sun-Earth Explorers

In the autumn of 1977, about a year and a half after Helios 2 arrived in orbit, another solar-significant launch took place at Kennedy Space Center. Like Helios, this was an international, multi-spacecraft project aimed at improving our understanding of the ways in which the Sun affects the near environment of Earth. This time America's scientific partner was the European Space Agency (ESA) representing the member nations of Germany, France, the United Kingdom, Italy, the Netherlands, Denmark, Belguim, Ireland, Spain, Sweden and Switzerland. The name of the mission was International Sun-Earth Explorers or ISEE.

ISEE was an ambitious and innovative project, involving coordinated observations by three spacecraft in widely separated and highly unusual orbital locations, with the U.S. responsible for the first and third elements and the Europeans for the second. In all three spacecraft the instruments for detecting and identifying plasmas in space were 10 times more sensitive than any ever flown before.

The first launch placed the first two spacecraft, ISEE-1 and ISEE-2 in the same highly elliptical Earth orbit with a closest point (perigee) of 480 kilometers (300 miles) and a highest point (apogee) of almost 145,000 kilometers (90,000 miles). Although in the same orbit, they were so controlled as to maintain a separation of 100 to 5000 kilometers (62 to 3100 miles). This long, looping trajectory sent them hurtling with their special instruments

This schematic of the ISEE mission shows the looping orbits of ISEE A and B (now 1 and 2) as they skim the Earth and then pass out of the magnetosphere, and ISEE C (now 3) far out at the libration point between Earth and Sun (not drawn to scale).

first deep into the ionosphere and then far out toward the Sun, cutting through the magnetopause boundary between near-Earth and interplanetary space. Their separation enabled them to make the same measurements at different locations at the same time and to observe at the same locations at different times.

Some 14 months after the first two spacecraft began operations, they were joined in space by the third. It took ISEE-3 78 days to reach its station, the most unusual ever assigned to a spacecraft. For two and a half months it flew straight out

toward the Sun—for a million miles—until it reached a location, called a libration point, where the gravitational attraction of the Sun precisely equals that of the Earth-Moon system. Once there, its onboard propellant system was directed to put it in a circular orbit around that point but above and below it, in a plane vertical to the ecliptic, so that to an observor on Earth who could see a million miles, ISEE-3 would appear to be circling the Sun.

From this unique location, ISEE-3 acts as an early warning station for ISEE-1 and ISEE-2 and for Earth. Its instruments continuously monitor the solar wind and other particles ejected from the Sun as a result of solar flares and prominences, coronal transients and other phenomena. Since it is a million miles from Earth and most solar particles travel at a million miles an hour, it picks up those particles and magnetic field structures a full hour before they are recorded by ISEEs 1 and 2 in Earth orbit, and before they are affected in any way by terrestrial influences.

As a practical matter ISEE-3 provides advance warning of disturbances in communications and other man-made technologies as a result of solar phenomena, especially solar flares.

As a scientific matter, the data provided by ISEE complements that from the Atmosphere Explorers. Whereas the AEs brought us new knowledge of the chemical processes in the high atmosphere caused by the Sun's ultraviolet radiation, ISEE investigated the interactions between the solar wind and the outer reaches of geospace which create the magnetosphere. In the course of that investigation, ISEE has observed the constant motion of the magnetosphere as it expands, contracts and changes shape in reaction to the solar wind. It has also measured the acceleration of particles both into the magnetosphere from the Sun and back toward the Sun from Earth, and recorded explosive mergings between the magnetic fields of Earth and Sun.

Thus ISEE, like Skylab and Helios, the OSOs, the Explorers and the Pioneers—and like their ancestors the medicine wheels and the primitive stone observatories, is providing us with more pieces to the puzzle which, when fitted together, will give us the understanding man has always sought.

Solar Maximum Mission

With the trio of ISEE satellites still making their coordinated measurements of the Sun's radiant energy and its effects on the environment of Earth, another spacecraft was launched into near-Earth orbit with a battery of advanced instruments designed primarily for the detailed study of solar flares which directly influence the phenomena being measured by ISEE.

The new spacecraft, launched in mid-February of 1980 into a circular orbit 570 kilometers (310 miles) above the Earth was part of a 19-month, 18-nation scientific project to study the Sun at the period of maximum activity in its 11-year cycle (Skylab, seven years before, had seen it at its least active). The international project was known as the Solar Maximum Year (August 1979 to February 1981) and coordinated investigations and observations from ground observatories and sounding rockets as well as satellites. The new spacecraft was thus named Solar Maximum Mission or "Solar Max."

Solar Max at work.

Solar Max is the first in a new generation of satellites called Modular Multimission Spacecraft, with standardized, prepackaged components for power supply, attitude control (pointing), data handling and communications, all mounted on a standard frame onto which any desired instrument package can simply be bolted and plugged in. The new spacecraft also is designed to be picked up in orbit by the Space Shuttle and returned to Earth, or for the simple replacement of its instrument module by Shuttle astronauts.

Six of Solar Max's seven instruments focus in on the development and the physical processes of solar flares, observing simultaneously for the first time in wave lengths from gamma rays all the way through x-ray and ultraviolet to visible red light. And those instruments work closely together under the control of an on-board computer. For example, when one sensor with a relatively broad field of view detects a spot on the Sun's surface emitting the hard x-rays which denote the beginnings of a flare, it signals the position to three other more narrowly focused instruments which instantly slew around to observe the spot in other wavelengths.

The seventh instrument measures variations in the total output of electromagnetic radiation by the Sun (the solar constant) with an accuracy of plus or minus one tenth of one percent. Nothing could be more important to life on Earth than the solar constant: a reduction of six percent would freeze the oceans solid. There is evidence that over a period of

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The two Dynamics Explorers in low and high polar orbits measuring and observing the Earth's auroras simultaneously from within and from far above.

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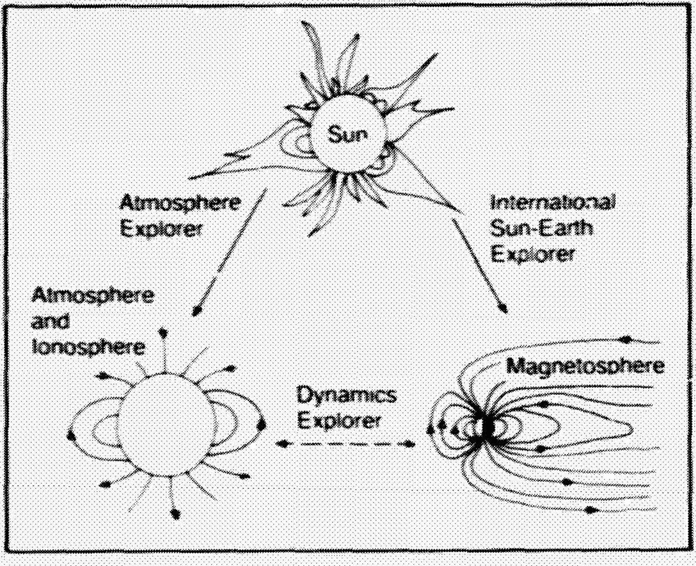


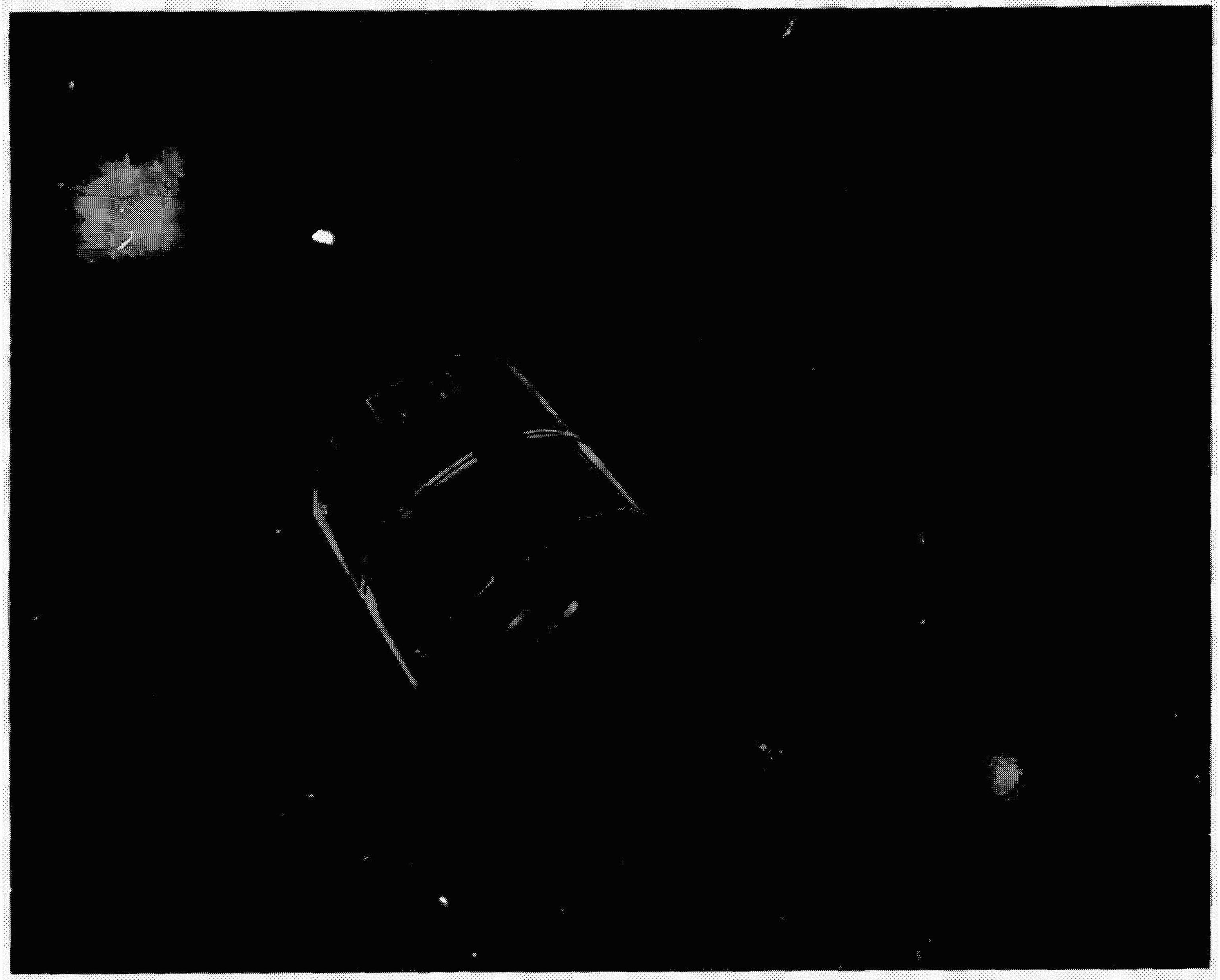
This triangle diagram shows the way in which the Atmosphere Explorers, the International Sun-Earth Explorers and Dynamics Explorer work together to give us an understanding of the interactions between solar radiation and the Earth's atmosphere, ionosphere and magnetosphere.

centuries the solar constant does vary significantly. Solar Max is designed to tell us how much and how often. It has already seen small decreases in the solar constant lasting about a week and apparently related to the number and areas of sunspots (when there are many sunspots, the solar constant decreases slightly.)

But why should we be concerned with flares on the surface of the Sun, invisible to the naked eye and 93 million miles away? Because flares on the Sun have direct and generally predictable effects on life on Earth. And because of the possibility that an understanding of the processes in solar flares, specifically affects the way in which their 100-million degree temperatures are confined and controlled by magnetic forces, and could teach us how to confine the heat of the plasma fuel in fusion reactors and thus end the energy shortage on Earth.

During the mission of Solar Max, flares and prominences and the sunspots and magnetic fields with which they are associated, are at their most numerous and most active, writhing and looping far out into space and causing geomagnetic storms on Earth with showers of charged particles which light up the Polar skies, overload power and telephone lines, blow out transformers, disrupt cable communications, degrade the performance of defense radars, endanger astronauts, cosmonauts and even passengers in high-flying airliners, and disrupt the ionosphere so that short range radio transmissions carry for long distances and long range messages get nowhere. And there are other effects which we strongly suspect but cannot yet prove, including weather and climate changes. When Solar Max completes its mission and the data are analyzed and matched with those from ISEE and the other facilities around the world dedicated to the Solar Maximum Year, we should have a greatly improved understanding of the Sun, its flares, and the steadiness of its radiation.

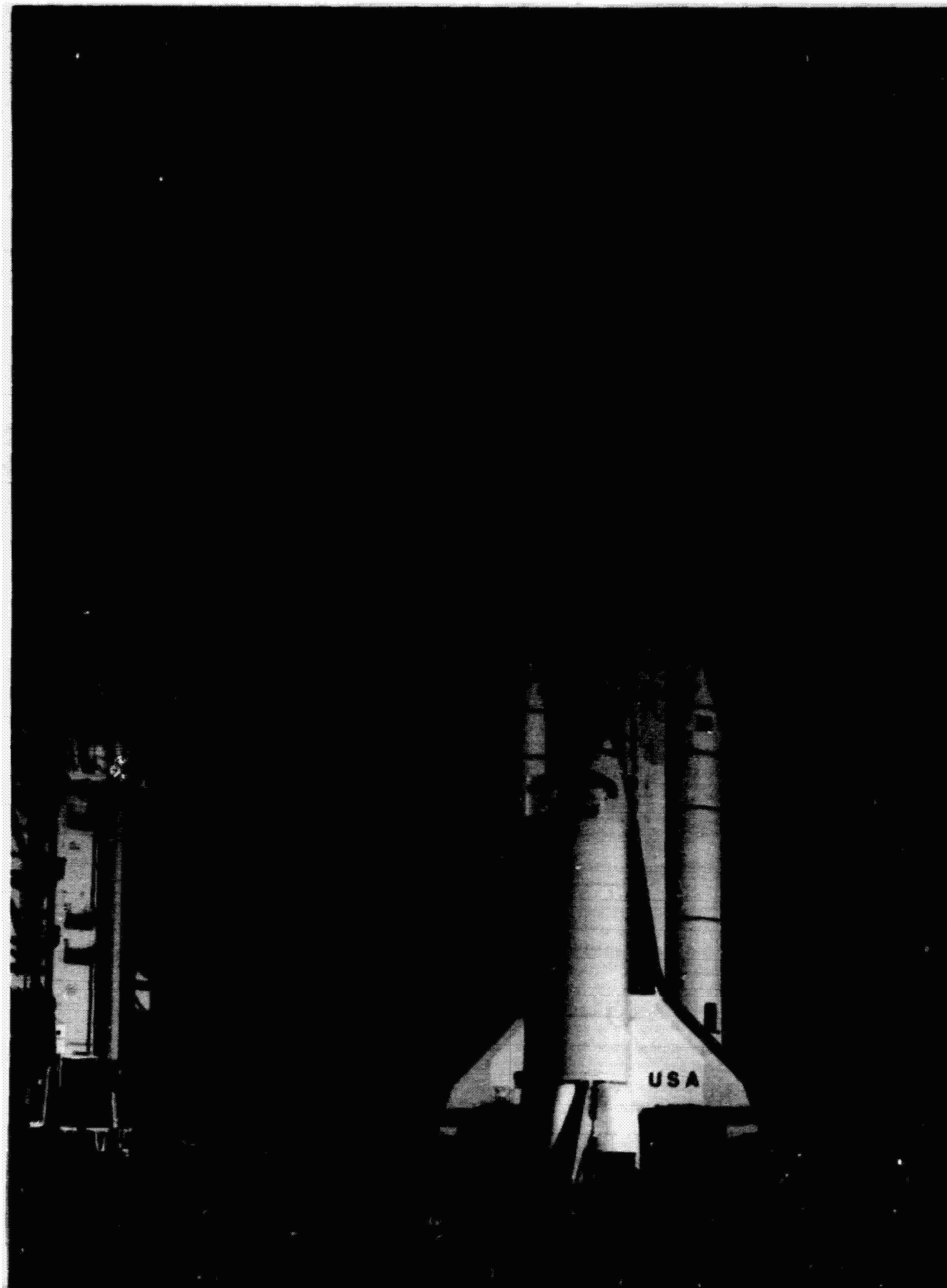
Solar Max has already discovered that the solar constant is not really constant at all but does vary by measurable amounts. And it has proven by observation at least one previously entirely theoretical concept related to the generation of flares. There also are plans to bring Solar Max back to Earth, refurbish, refit, and relaunch it in the middle eighties to investigate the Sun's large scale magnetic fields and the three-dimensional structure of the corona.



Dynamics Explorer

In the spring of 1981, another dual spacecraft mission was about to begin. It is in a sense a follow-on to ISEE and the Atmosphere Explorers of the seventies. Where the AEs investigated the production of the ionosphere through the interactions between solar radiation and the atmosphere, and ISEE studied the production of the magnetosphere through interactions between the solar wind and the outer reaches of geospace, the new mission, Dynamics Explorer, closed the loop, examining the couplings and interactions between the atmosphere, the ionosphere and the magnetosphere.

Both DEs will be in polar, not equatorial, orbits, one very high, one low. The low spacecraft will measure the energetic particles and characteristics of the Earth's high atmosphere with special emphasis on the polar areas where the auroras occur. Its high partner will simultaneously observe from a distance. In effect one watches and measures from aloft while the other flies through the area of interest, measuring directly. Together they should enable us for the first time to understand the nature of the flaring auroral displays which have awed, intrigued and frightened people for a million years.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III

THE DECADE OF THE EIGHTIES

The Space Shuttle orbiter COLUMBIA, mated to its huge external fuel tank and its two solid rocket boosters as it arrived at the launch pad to prepare for its first flight. Shuttles large cargo bay and weight capacity will permit bigger, more capable spacecraft in orbit to study Sun-Earth relationships.

By the spring of 1981 the Space Age was in its twenty-fourth year. For nearly a quarter-century mankind had been exploring and surveying the space around his home planet (geospace) and intensively studying his local star, the Sun, from newly acquired and unobstructed vantage points far beyond the atmosphere of Earth. Now, in the decade of the eighties the emphasis in humanity's unceasing effort to understand the complex relationships between Sun and Earth has shifted. Although some exploration and surveying remain to be done, the concentration of effort has turned to explanations and understandings of that which had already been discovered, mapped and measured. Increasingly, research programs and projects in solar-terrestrial relationships are designed to obtain data with which fairly specific questions can be answered, to delineate the pieces needed to fill the gaps in the puzzle and to complete the picture.

Between 1957 and 1981 we had added to the storehouse of human knowledge to a degree never equaled in any comparable period of time. It has been calculated that our ability to receive and analyze the various wavelengths of the electromagnetic spectrum radiating from the Sun and other sources in the universe increased during those years by 16 orders of magnitude, or 160 times. But there was still infinitely more to be learned than was known, even in the relatively restricted field of Sun-Earth interactions. In the words of the Nineteenth Century English biologist T. H. Huxley, *"The known is finite, the unknown infinite; intellectually we stand on an islet in the midst of an illimitable ocean of inexplicability. Our business in every generation is to reclaim a little more land."*

Research Goals

The human generations of the final fifth of the Twentieth Century have selected specific areas of the unknown for reclamation.

One is the exact nature of the nuclear process that drives the solar furnace and produces its energy. We think we know it in a general way—the conversion of hydrogen to helium with a resultant release of energy. But there is an unsolved problem with this explanation. If the calculations of nuclear physicists are correct, such a nuclear reaction should release predictable quantities of sub-atomic particles called neutrinos that travel at the speed of light and have no mass (weigh nothing). But the best measurements we are able to make show only about one third as many neutrinos coming from the Sun as our calculations show there should be.

Are our measurements faulty?

Is our knowledge of the nuclear processes which generate neutrinos deficient?

If our measurements are trustworthy and our nuclear physics reliable, there is something important we don't understand about what is happening in the unimaginably hot, dense and turbulent interior of the Sun where the energy is generated which bathes the Earth and geospace.

A second area of knowledge which needs to be reclaimed is the way in which

the Sun's energy, direct and indirect, is generated, stored, transformed and released in the fluctuating, interactive and complex space environment of our planet. The explorations and surveys of the last 24 years have given us a sketch and a few key pieces of the puzzle. We need now to fill in, flesh out and color to complete the picture.

Finally, how do the energy processes in geospace affect modern, technological human society? What are the cause and effect relationships between the interaction of solar and terrestrial energetic particles and the weather and climate on Earth which so directly affect us all? We want to know what gives the Sun its energy, how that energy reacts with the Earth's environment in space, and how those reactions affect us as the dominant life-form on our planet.

We already know that radio waves from commercial power lines are strong enough to alter some characteristics of Earth's natural radiation belts.* There is strong evidence that fluorocarbons, rising to the stratosphere from millions of convenient aerosol products, are thinning the ozone layer which shields us from damaging ultraviolet radiation. And carbon dioxide discharged into the atmosphere from the burning of coal, oil and gas could very well change Earth's climate in harmful and potentially disastrous ways.

So we need to know not only how the Sun affects the Earth's near-space environment, but how we ourselves affect it as well.

*Radio signals transmitted into space from Antarctica have triggered radio emissions called "whistlers" resulting from the discharge of natural energies out in the magnetosphere, and similar triggering has been caused by power lines in Canada. The long-term effect of this phenomena is not known.

The Space Shuttle

In driving for these research goals in the decade of the eighties we will have the use of a new tool which will expand all our capabilities in space—the new Space Transportation System or reuseable Space Shuttle. Launched like a rocket but landing like an aircraft, the Shuttle orbiters are the first vehicles ever designed to maneuver in both air and space.

When the Shuttle first flew in the spring of 1981 it opened a new era in space transportation, an era of regular, practical, economical manned access to space, an era in which for the first time space, like the sea and the air, becomes an environment in which man can live and work.

With its huge cargo bay, 18.3 meters long and 4.6 meters in diameter (60 feet by 15 feet), its eventual payload capacity of almost 30,000 kilograms (65,000 pounds), its ability to perform final checks in orbit and to repair, replace or retrieve orbital payloads, Shuttle provides new and revolutionary capabilities. Designers and engineers no longer must go to the expense of building spacecraft for extreme reliability, with redundant systems, which will last almost indefinitely and yet must be folded into the nose of a rocket, must withstand large accelerations and vibrations during launch and then deploy and "turn on" in orbit.

Four hundred and eighty-seven Shuttle flights are scheduled in the next dozen years with approximately a launch a week when operations reach their full tempo. This volume of space traffic and the Shut-

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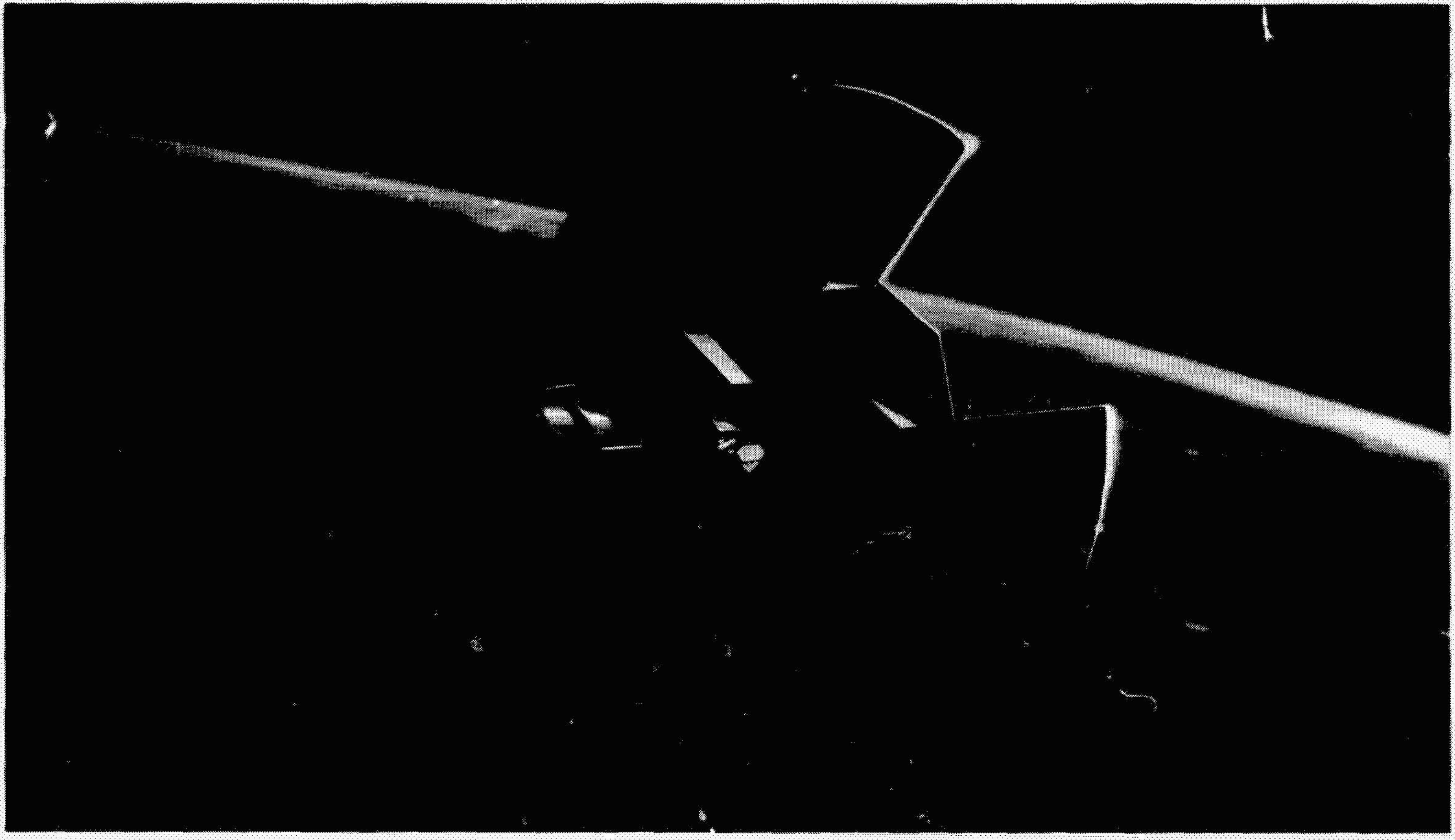

tle's reuseability will bring the cost of putting payloads in space far below that of today when the entire very expensive launch vehicle is discarded with every flight. It is estimated that Shuttle launch costs for a given payload will be from one-third to two-thirds that of expendable rockets. This means that for a given amount of money we can put a more capable spacecraft in orbit.

Using both expendable launch vehicles and the Shuttle during the transitional years, the search for a better understanding of the processes and interactions in the middle atmosphere (mesosphere) is planned in two consecutive and complementary steps.

Solar Mesosphere Explorer (SME)

The first step will be the launching of the Solar Mesosphere Explorer, a spacecraft designed to tell us how the distribution of ozone is altered by changes in incoming solar radiation and, secondarily, to obtain measurements of changes in the density of the protective ozone between altitudes of 30-80 kilometers (19-50 miles) and the causes of those changes. We know that above and below

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Solar Mesosphere Explorer 550 kilometers (340 miles) above the Earth studying atmosphere ozone, the processes which form and destroy it and the ways solar radiations change it.

those altitudes the distribution of ozone changes very slowly, with the seasons; but, in the area between, distribution is governed primarily by photochemical processes in which ultraviolet radiation from the Sun is the major influence. Since SME will be flying at the period of maximum activity in the solar cycle, it will be able to measure the effects of maximum variations in ultraviolet energy.

With that knowledge we will be able to take an important step: the study of the radiative, chemical, and dynamic interactions, not separately or at separate levels, but as they occur throughout the entire upper atmosphere. The vehicle by which that step will be taken, still in the stage of advanced planning will be two Upper Atmosphere Research Satellites. They will have three goals:

(1) to understand what controls the structure of the upper atmosphere;
(2) to understand how the upper atmosphere responds, reacts and adjusts to both solar and man-made disturbances (such as pollutants); and
(3) to understand the relationship of the upper atmosphere to weather and climate on Earth.

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The Space Shuttle orbiter using its manipulator arm to retrieve a satellite for repair, refurbishment or return to Earth.

Upper Atmosphere Research Satellite (UARS)

The Upper Atmosphere Research Satellites will be launched by the Space Shuttle in the mid-eighties and will have lots of scientific company in space. They will be members of a team of far-flying, automated extensions of human intelligence which for the first time will be able to look simultaneously at the complete Sun-Earth energy chain. UARS and their orbiting peers will see, as an integrated whole, first, the origin, ejection and flow of energy and matter from the Sun through the solar system; second, the interactions between that flow and the Earth's magnetosphere; and finally, the reactions of that energy with our upper atmosphere.

There will be two other chief elements in this task force of space vehicles if our present plans are carried out. The first, the International Solar Polar Mission (ISPM) is the bolder and more dramatic, but the other, Origin of Plasmas in the Earth's Neighborhood (OPEN), balances those qualities with the complexity of four spacecraft and with ambitious, advanced technology.

An artist's concept of the Solar Polar spacecraft approaching the sun.

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International Solar Polar Mission (ISPM)

As its name signifies, the Solar Polar Mission will look at the north and south poles of the Sun—active, interesting, important, solar areas which we can see from Earth only at a sharp angle. The ISPM spacecraft will look down on them from a distance of about one AU. To do that they must become the first spacecraft to fly out of the ecliptic, the plane in which the Earth and all the other planets and moons in the solar system revolve around the Sun.

To envision the ecliptic, think of a long-playing record album. The Sun is in the hole at the center with the edges of the hole tracing its equator. The planets move around the Sun in the grooves of the album—Mercury, closest to the Sun, then Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto, in that order.* (There is an easy way to remember the order, just use *M*y *V*ery *E*asy *M*emory *J*ogging *S*ystem *U*sing *N*ine *P*lanets.) The album is the ecliptic, and thus far all our spacecraft have stayed in that plane. But the Solar-Polar voyagers will soar up over it and down under it, with both spacecraft passing over both poles of the Sun.

According to plans, the two spacecraft, one provided by NASA and the other by the European Space Agency (ESA), will be launched in sequence from the Space Shuttle in near-Earth orbit on a 16-month flight (within the plane of the ecliptic) to Jupiter—away from the Sun. On that first leg one will be trailing the other at a distance of only about three million kilometers (1.9 million miles) so that their instruments will be able to measure identical solar wind characteristics as first one and then the other passes a given point.

As they approach the colossal, whirling gas ball of Jupiter—with more mass than all the other bodies of the solar system, excluding the Sun, combined—the two spacecraft will separate to pass closely on opposite sides of the giant planet in such a way that Jupiter's immense gravitational pull will hurl them, like stones from a slingshot, "up" and "down," out of the ecliptic and back in long elliptical trajectories toward the "top" and the "bottom" of the Sun.

*This is a grossly simplified analogy used only as an aid to understanding. Planetary orbits, for example, are not circles but ellipses, and the scale of distances between planets is here greatly compressed.

A: ·st's conception of one of the Solar Polar spacecraft approaching the Sun from high above the ecliptic in previously untravelled space for a first good look at the solar poles.

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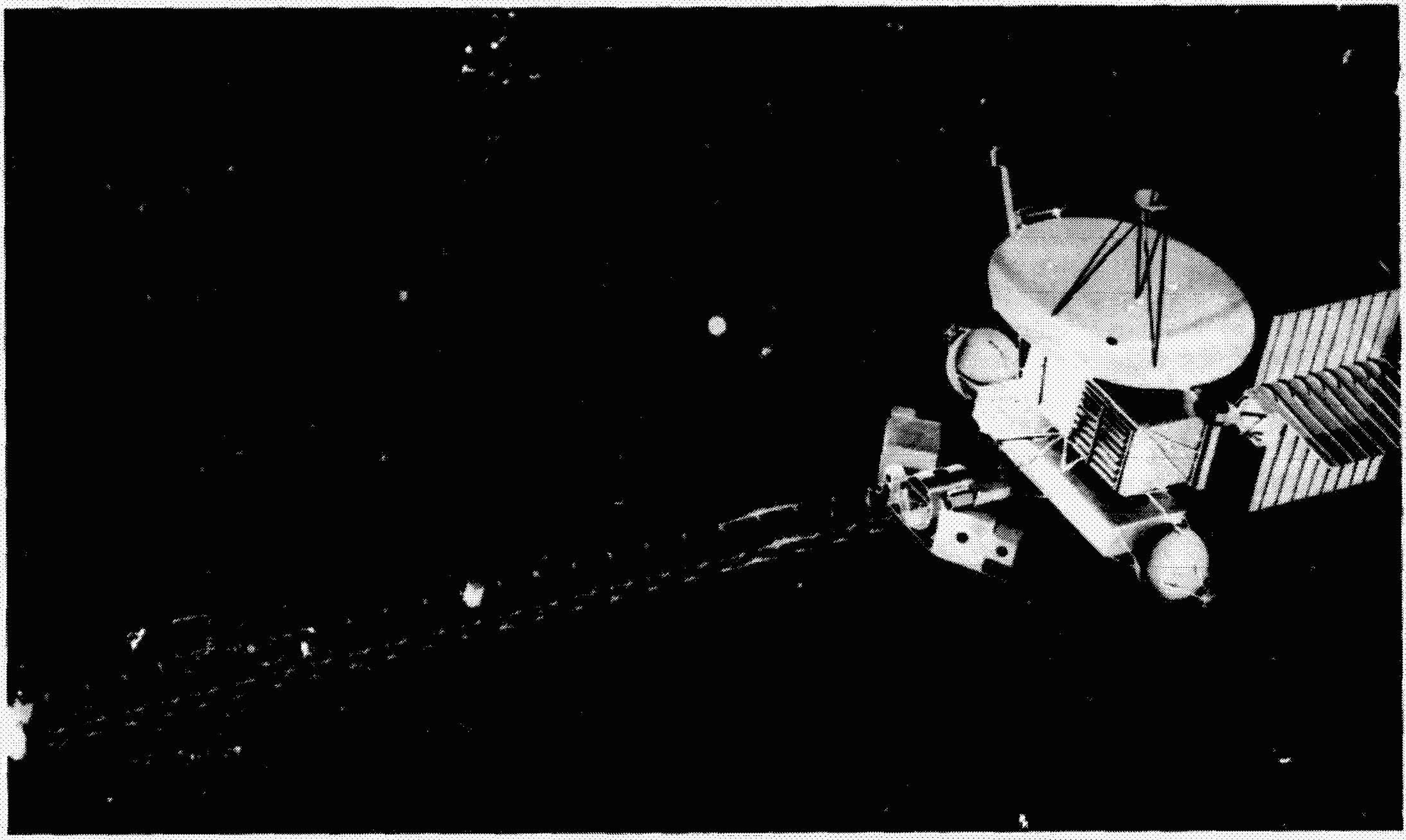


The Solar Polar spacecraft will pass simultaneously over the north and south solar poles, then swoop on opposite courses, "up" and "down" through the ecliptic to change places, so that each spacecraft passes over both poles within a period of six months, before being flung by the Sun's gravity back toward Jupiter. Total time from launch to the second polar passages—four years and four months.

What do we expect to gain from this truly epic scientific adventure?

In general we will gain a better understanding of some of the most important solar phenomena that shape and control the space environment of Earth.

Specifically we will add to our knowledge in three areas of great interest.

First, the solar poles are dominated by the large coronal holes first observed by the OSOs and confirmed and examined by Skylab. It is from such coronal holes that high velocity solar winds and intense magnetic fields are ejected to sweep the solar system. Because of the slower rotation rate of the Sun and weaker magnetic fields at its poles, the solar wind from the poles should be simpler in density and direction and more representative of that which pervades interplanetary space than the more complicated wind from lower solar latitudes which carries most of the particles which strike the atmosphere of Earth.

Second, the passage of the spacecraft out of the ecliptic plane will enable their instruments to examine the full spectrum of cosmic rays flowing through the solar system from interstellar space without interference from the spiraling magnetic field of the Sun in the ecliptic plane. This is important because cosmic rays—high-velocity nuclei of heavy atoms—are essentially messengers which carry information that we cannot obtain from any other source about the galaxy beyond the solar system.

Finally, the Solar Polar Mission will allow us, for the first time, to study the Sun itself from an entirely different viewpoint. Among other things we will be able to examine the three-dimensional structure of the corona and the ways in which it changes with time. By studying them from above the solar poles we may also be able to determine whether or not the huge coronal transients photographed so spectacularly by Skylab are associated with the solar flares which we know affect radio communications, power lines, and other similar man-made systems on Earth.

Origin of Plasmas in Earth's Neighborhood (OPEN)

While the Solar Polar spacecraft are winging between the planets and looping around the Sun, another mission, closer to Earth, is planned to furnish complementary data, supplying other puzzle pieces to help complete the picture of Sun-Earth energy interactions. That mission is Origin of Plasmas in Earth's Neighborhood (OPEN). OPEN's four spacecraft and their computerized ground facilities at NASA's Goddard Space Flight Center in Maryland will provide for the first time a means of collecting data on simultaneous events throughout the whole complex, changing and interacting envelope of geospace. Where previous space systems will have furnished single-point measurements which can be joined to form a sketch, an outline, it will be OPEN's task to transform that sketch into a comprehensive and comprehensible blueprint.

What we hope to be able to gain from that blueprint are three key pieces of knowledge which together can unlock the secrets of the nature of geospace and its effect on the Earth and its inhabitants. The first key is an accurate assessment of the flow of energy and mass throughout geospace. The second is an understanding of the way in which the various components of geospace interact and of their cause and effect relationships. The third key is an assessment of the effects of geospace phenomena on the lower levels of our atmosphere where we live.

By the mid-1980s the steady advance of U.S. technology, sparked by the uniquely American teamwork of government, industry and the academic community, will have provided OPEN with two new advantages—greatly improved instruments and Space Shuttle launching.

Recent advances in instruments which measure space plasma have given us the ability to determine the properties of plasma, to distinguish between different types of charged particles and to measure electric and magnetic fields with the broad range and high resolution required to solve the complex problems of geospace.

The roomy cargo bay of the Space Shuttle, and its ability to lift heavy payloads into near-Earth orbit, permit the OPEN satellites to be larger and heavier than previous spacecraft and to carry their own propulsion systems with ample supplies of fuel for adjusting or changing orbits.

Thus the OPEN spacecraft will be effectively compact, spaceborne, automated laboratories as opposed to previous scientific satellites which have been essentially measuring instruments.

The four OPEN flying labs will be placed in unusual and changeable orbits.

One, the Interplanetary Physics Laboratory or IPL, will soar out 1.5 million kilometers (a million miles) ahead of the moving Earth and take up a "halo" orbit similar to that of ISEE-3 at the libration point between Earth and Sun where the forces of gravity are equal. There it will measure the incoming solar wind, magnetic fields and particles, and act as an early warning station for its sisters.

A second, the Polar Plasma Laboratory, or PPL, will read solar wind entry into the magnetosphere, the output of particles from the ionosphere and the deposition of energy into the Earth's atmosphere at high latitudes. It will take those readings from a looping orbit which carries it over both the poles of Earth, first with an apogee (maximum altitude) of 90,000 kilometers (56,000 miles) and later with an apogee of only 25,000 kilometers (16,000 miles). While the PPL loops around the poles, the third spacecraft, the Equatorial Magnetosphere Laboratory, or EML, will circle Earth's equator at altitudes between 6000 and 70,000 kilometers (3600 to 43,000 miles), where for a year it will measure the storage of energy near Earth in the vicinity of the equator and study the entry of solar wind particles into the magnetosphere in the lower latitudes. Later in the mission EML will use its own propulsion system to move back into Earth's long magnetotail and conduct joint observations with the fourth spacecraft.

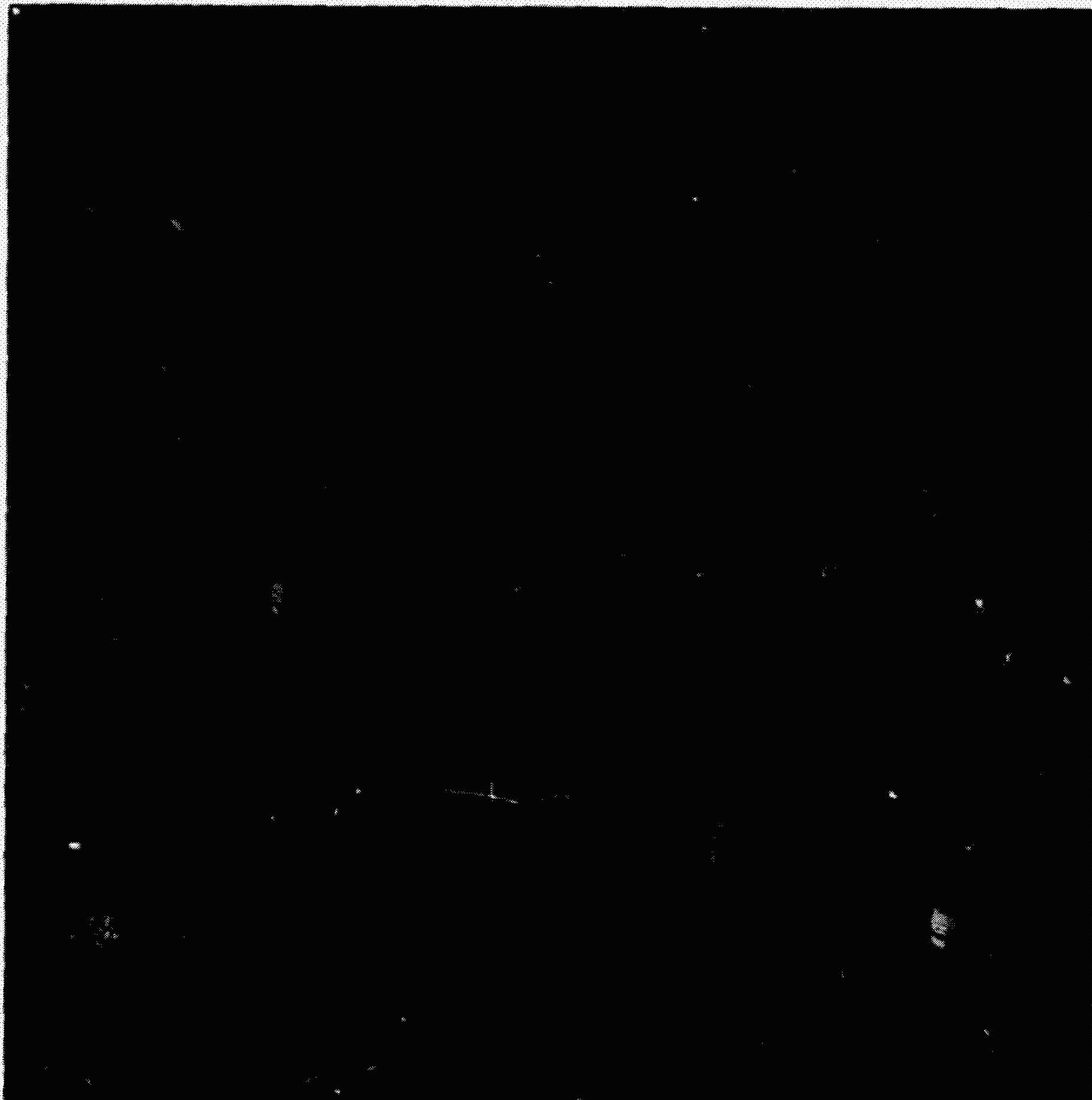
That fourth satellite, the Geomagnetic Tail Laboratory, or GTL, will make the first complete survey of the magnetotail extending far back in the wake of Earth as it plows around the Sun through the flood of energetic particles from the solar wind. GTL will use a new and unique technique involving periodic gravitational kicks from the Moon to keep it inside the comet-like magnetosphere tail.

The data from PEN, UARS and other systems mapping and measuring geospace will help in similar research far from Earth as well. In the same way that the Sun, as our local and sample star, can teach us the nature of other stars, so does the conveniently close and readily measurable geospace environment teach us what to expect in the environments of other planets. Thus, what OPEN learns about near-Earth plasmas and phenomena will be used to plan the orbits and instruments of Galileo, due at Jupiter in 1986.

While UARS is studying the upper atmosphere, the Solar Polar spacecraft are soaring over the ecliptic and the flying automated labs of OPEN are piercing the anatomy of the magnetosphere, they will be joined for periods of a week or so at a time by the first manned scientific laboratory in space since Skylab and with a similar name—Spacelab.

Spacelab

Spacelab, designed, constructed, equipped and paid for by the European Space Agency (ESA), at a cost of over a half a billion dollars, to fly in the cargo bay of the Space Shuttle, is an example of constructive international cooperation in space. It is a fully equipped modern laboratory in which as many as four scientists can work in shirt-sleeve comfort. The first Spacelab mission will carry no fewer than 38 scientific instruments from the United States, Europe and Japan.



Although that first flight will be primarily concerned with checking out the Spacelab and its various facilities, the embarked scientists will also take measurements and conduct experiments in the physics of space plasma and the high atmosphere. Succeeding Spacelab flights will conduct a carefully planned, step-by-step study of the atmosphere, the magnetosphere, and space plasmas.

The manned space laboratory has important advantages over automated spacecraft however advanced and versatile. The advantage of on-the-spot human judgment, decision-making and improvisation are obvious. But the big manned lab can carry aloft heavy scientific equipment and devices and supply them with the large

Sketched here are the two Solar Polar spacecraft soaring over the poles of the Sun at the same time that the four flying laboratories of OPEN, the two satellites of UARS and Spacelab conduct coordinated investigations of Sun-Earth energy processes.

amounts of electrical power they require. They enable Spacelab to conduct not only observations and measurements, but active experiments as well. For example, traceable ions (electrically charged atoms) can be deliberately injected into given areas of geospace and their movement and behavior visually tracked from space and from the ground by the fluorescence they emit. Since such particles are influenced by electrical forces, the electric fields in geospace can be studied.

An experiment of this kind is planned for the mid-eighties using two spacecraft launched from the Shuttle. One, supplied by West Germany, will release barium into the solar wind outside the magnetosphere. The other, furnished by the United States, will later measure the energy, location and movement of the barium ions *inside* the magnetosphere. Correlation of data from the two spacecraft will give us an improved understanding of the process by which solar wind particles enter the magnetosphere. In other active experiments, charged particle beams from heavy Spacelab ion and electron accelerators can be used to map the structure of phenom-

An artist's concept of the Infrared Astronomical Satellite searching space for solar infrared activity.

ena in geospace electric fields, and even to stimulate the aurora artifically. This will give us insights into the quantities and energies of magnetospheric particles required to create different intensities of Northern Lights.

In still another example, Spacelab makes possible the use of Lidar, (Light Detection and Ranging, an amplified and intensified light system akin to laser) to measure the composition of portions of the high atmosphere hard to reach with other systems.

Like the Space Shuttle itself, Spacelab is so new, so promising, so potentially versatile that we won't even know what we can do with it until we have acquired operational experience in space.

Solar Optical Telescope

One of the things we do know we can do with Spacelab is to operate a revolutionary new Solar Optical Telescope which will be ready for installation by late 1985 or early 1986. With a lens aperture of one and a quarter meters (four feet) and no obscuring atmosphere to interfere, the new telescope will be able to observe small features on the Sun with 10 times the magnification (resolution) of ground based instruments and in all wave lengths from ultraviolet to infrared.

Solar Probe

One of the most interesting and challenging projects planned for the middle years of the eighties is a spacecraft that will fly past the Sun, penetrating the corona, at the searingly close range of only three solar radii, about 4.2 million kilometers or 2.6 million miles. At that distance the intensity of the Sun's radiation, including lethal gamma rays, x-rays, ultraviolet, and extreme heat, will be equal to that of about 2500 Suns. The engineering problems involved in protecting the spacecraft's delicate sensors in the immediate vicinity of that blazing nuclear inferno are immense. And the mission is further complicated by the difficulty of data transmission and control commands through the violently noisy radio emissions from the Sun.

The scientific rewards from the Solar Probe—unprecedented knowledge from on-the-spot measurements of the structure, composition and dynamics of the corona and of the solar wind at its source, plus valuable new data from experiments in relativity and gravitation—are well worth the demanding engineering effort.

Planned Space Programs

Several other ingenious and imaginative projects are being planned to gain more knowledge of the Sun and of geospace, and thereby a better understanding of the relationships between them.

One spacecraft will study the evolution and rotation of coronal holes, and the distribution of the bright points which show up in x-ray observations of the Sun, as clues to the nature of the magnetic fields below the surface. It will also take measurements of the corona from within

the plane of the ecliptic while the Solar Polar satellites are observing from above and below.

An x-ray telescope, observing from Spacelab, will also study the origin and development of coronal holes and the coiling magnetic loops which appear to be associated with them.

Another project will investigate the turbulence which apparently occurs continuously and everywhere in interplanetary plasma.

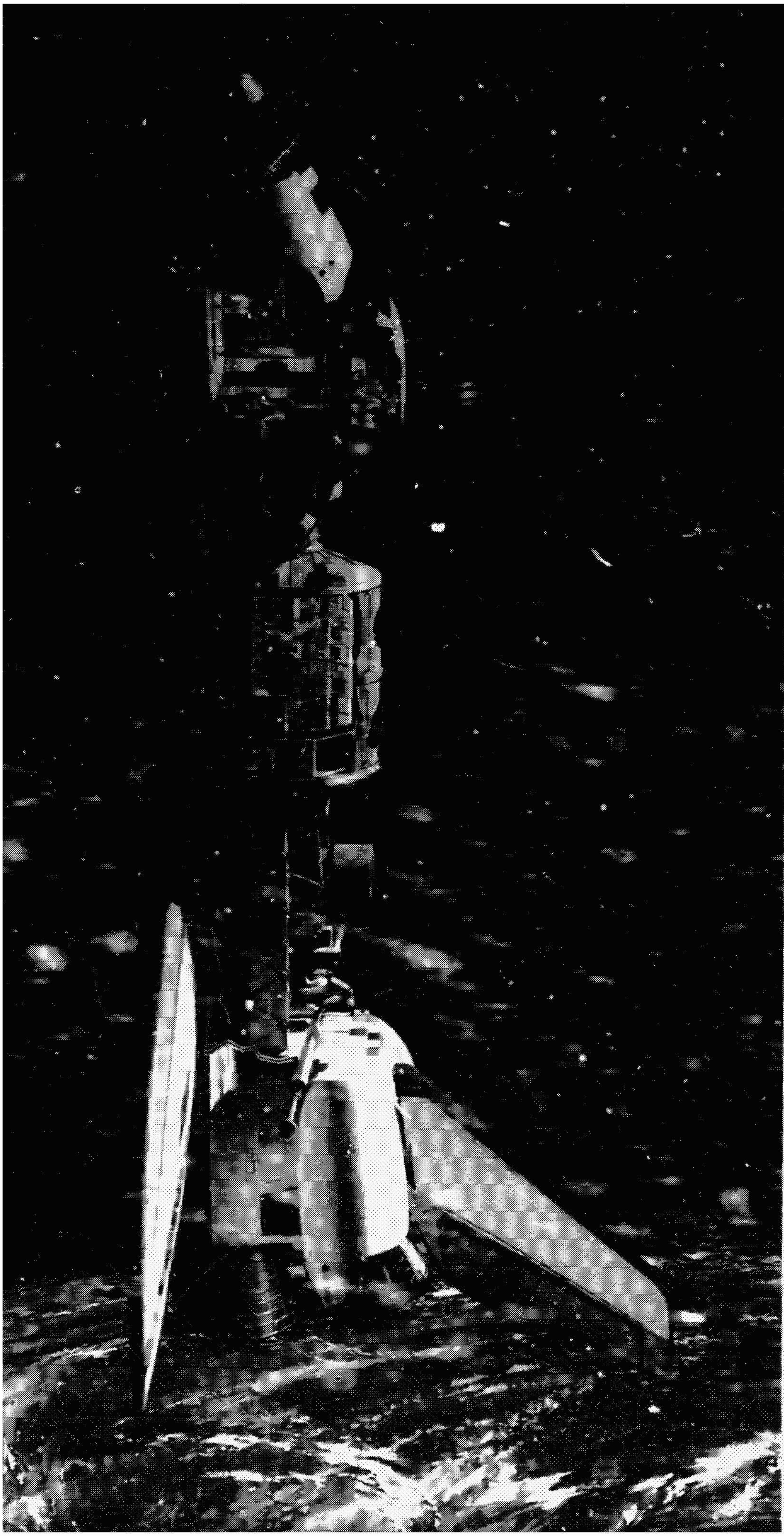
Beginning in the last half of this decade an effort will be made to explain the mystery of the lost neutrinos by means of a spacecraft designed to make a comprehensive study of the dynamic processes in the interior of the Sun by close observation of their effects on the visible solar surface.

At the same time, as the next solar maximum approaches, plans call for the Shuttle to place in orbit a huge disk pierced by thousands of tiny pinholes. Then, as far as one kilometer down-Sun from the disk, so placed that the disk appears to cover exactly the sphere of the Sun, a detector instrument package will be placed which will look through the pinholes in x-ray wavelengths to study the corona and events on the Sun in high resolution. Ideally, this "pinhole satellite" should be observing the Sun at the same time that the Solar Probe is making its *in situ* (on the spot) measurements of the corona.

As a follow-up to the Solar Polar flights and the Sun-grazing Solar Probe, other plans are being drawn to put several spacecraft in close orbits around the Sun. Such a team of orbiters would not only monitor the flares, prominences, transients, Sun-spots, bright x-ray spots, coronal holes and other solar phenomena but would also serve as distant early warning devices in the same manner as ISEE-3 and OPEN's Interplanetary Physics Laboratory far back toward Earth.

Another system planned for studying the nearly inaccessible level of the atmosphere which is too high and thin for aircraft and too low and dense for spacecraft, will use the boldly logical technique of towing instrumented satellites from the Space Shuttle on a tether as long as 100 kilometers (62 miles). With the Shuttle in safe orbit above the atmosphere, the tethered satellite would be towed through the level of interest and then reeled back into the cargo bay.

By the end of the decade, knowledge of Sun-Earth relationships will have increased sufficiently to warrant the establishment of permanent Solar Terrestrial Observatories in space. The first STO's will be relatively small and will have essentially the same instrumentation as contemporary versions of Spacelab. Later models will incorporate specially designed instruments and will be large enough to require on-orbit assembly of several Shuttle-loads of materials. The function of these observatories will be to link together all the knowledge we have acquired about the separate elements of the Sun-Earth system into a cause-effect chain by continuous observation using advanced instruments and scientific techniques. An understanding of those cause-effect relationships can in turn give us the long-sought ability to predict the effects of disturbances in the system—such as solar flares and high-speed squirts of solar wind—in much the same way that we can now warn of the approach of hurricanes or of weather conditions favorable for the development of tornados.



Artist's concept of the Space Shuttle orbiter at work with Spacelab in the cargo bay. Aft of Spacelab are pallets with experiments which require exposure to space.

IV

THE FUTURE

This photograph of the Sun was taken through the Solar Telescope of Skylab. Regions of most violent activity on the Sun are restricted to two parallel belts on either side of the solar equator. At the time of Skylab's flight active regions were found in the two low-latitude bands shown here. In hard and soft X-rays, individual active regions stand out in sharp contrast, indicating that they are areas of locally high temperature

How far then have we come in our efforts to understand the nature of the Sun-Earth relationship on which we are so utterly dependent? What do we still need to know to achieve that understanding? How much of that knowledge will we have reclaimed from the ocean of the unknown by the end of the decade with the investigations in progress and planned? What kinds of things might we do after that to complete the understanding we seek and make use of it for the long-range benefit of mankind?

New Concept of Sun-Earth System

We do know that we have achieved a new concept of the Sun-Earth system as a result of observations and measurements from space. We see it now as an energetic and dynamic system, fluctuating, vibrating, changing shape and interacting in rhythms which vary in frequency from minutes to millenia. This concept should come as no surprise since it matches the familiar environment at the bottom of the ocean of air where we live our lives, and where the days and nights, the seasons, temperatures, pressures, wind velocities, tides and weather patterns are all in constant change, all fluctuating with their own rhythms of differing durations. Indeed as men and women born of the planet Earth we live and die by our own rhythms of pulse, brain wave, and function, of youth, maturity, age and death, and we witness the rhythmic arrival and departure of human generations.

Into this concept we incorporate spectacular solar flares which rise and fall in minutes, huge solar prominences which have lifetimes measured in hours and days, the rotating spirals of the Sun's magnetic field which seep across the Earth each week, yearly fluctuations in the electrical properties of the ionosphere, sunspot cycles of 11 years, and solar magnetic polarity cycles of 22 years. And we have increasing evidence of solar cycles with much more measured rhythms, cycles with frequencies of centuries. There is evidence from tree-ring measurements that the "Little Ice Age" in Europe from the 1640's to the early 1700's was not an isolated phenomenon but that it resulted from one of the almost complete century-long shut-downs of solar activity which have occurred with some regularity for at least the last 7000 years. The Earth's magnetic field waxes and wanes and reverses polarity in cycles of half a million years. And what about the ebb and flow of the great continental ice sheets? Do they result from rhythmic changes in the solar constant every half a million years or so?

In this new concept we see the Earth's magnetosphere pulsating and changing shape under the changing pressures of the solar wind, with varying quantities of assorted energetic particles penetrating the magnetosheath to affect our atmosphere in many ways. And we see our own Earth with energy-release cycles of its own.

It is a challenging and exciting concept, made more so by building evidence that solar and earthly rhythms interact to affect the human environment in important and eventually predictable ways.

Beyond the achievement of that sweeping new concept, we also can be certain that we have learned more in the few years that we have had access to space than in all the decades, centuries and millenia which went before. We have been able to stock the shelves of the storehouse

of human knowledge with new discoveries and concepts, with new understandings of the nature of geospace and of the workings and phenomena of the Sun.

Two thousand years ago a curious human being discovered that certain ferrous ores and metals exhibited a peculiar property we have come to know as magnetism. Twelve hundred years later that property was used for navigational purposes and led to the discovery of new worlds and the dramatic expansion of human knowledge. In the last century and a half, discovery of the basic significance of magnetism to the structure of matter has become the basis for much of our present-day technology.

Leonardo da Vinci worked out the basic principles of aerodynamics around the turn of the Sixteenth Century. It was 400 years before the Wright brothers took that knowledge from the shelf, added the internal combustion engine and man left the ground in powered flight.

Happily, in recent years the interval between the attainment of knowledge and its use to improve the human lot has shortened. It was, for example, only about 30 years after that first faltering flight down the dunes of Hatteras that practical air transportation became a reality, cutting human travel times from days to hours.

Current Knowledge

In the use of our new knowledge of Sun-Earth relationships, we have been able to do much better. After only a few years of study from space we are able to tell several days in advance when a particularly active region on the Sun is likely to produce major flares. Thus we are able to predict them, and the flare-caused geomagnetic storms which disrupt communications and power transmission on Earth, with sufficient reliability and timeliness to establish a working warning service. NASA now provides this information regularly to the National Oceanic and Atmospheric Administration (NOAA), which, in turn, warns the Department of Defense, the Federal Aviation Agency, and other organizations which could be affected by the geomagnetic disturbances.

Less positive but still of value is the fact that we can pretty well predict the day or two out of each seven when we will not be able to forecast storms as accurately as at other times. Those days come immediately after the sweeping spirals of the Sun's magnetic field cross the Earth and reverse polarity.

And since the cycles of drought in the high plains of the United States have come with devastating regularity every 22 years for the past three centuries, we can warn farmers and cattlemen in those states (the Dakotas, Nebraska and the eastern sections of Montana, Wyoming and Colorado) to take precautions. The next drought is due in 1998.

The trouble with these new-found capabilities, as helpful as they are, is that they are mainly the results of empirical data. We know they work but we don't really know why.

Understandings Required

If we really understood the processes by which large amounts of magnetically stored energy are released in solar flares, we could greatly improve the accurac, and timeliness of our predictions and warnings and perhaps even develop ways to reduce or even cancel their disruptive effects. If

we really understood the way in which magnetic events on the surface of the Sun 93 million miles away regularly *reduce* our weather forecasting ability here on Earth, we could use that knowledge to *improve* our forecasting ability. If we really understood the cause-effect relationship between the double solar-activity cycle of 22 years and the high-plains droughts, we could probably predict the specific areas where drought would occur and its duration and severity. This understanding is especially important because of its global economic and geopolitical ramifications. For example, a shortening of the growing season in Siberia by only three weeks causes a serious reduction in Soviet grain production which requires the Russians to buy grain on the world market, which affects wheat and corn farmers in Iowa, Nebraska and Argentina, which causes political repercussions in the United States and the Soviet Union, and on down a continuing chain of cause and effect. Furthermore at the time of the last high-plains drought in 1976, there was an apparently related shifting of the monsoon winds away from India, which depends heavily on that rainfall to grow the crops which sustain its 650 million people. Consider the benefits to human life, the world's economic health and international relations, of an understanding which would permit advance warning and advance actions to minimize the harmful effects of these phenomena.

But understandings of the processes which create solar flares, of the way in which solar magnetic changes work to degrade our weather forecasting, and even of the cause-effect relationships between solar activity and periodic droughts, would provide us only with answers to three specific parts of a much larger, more difficult, and vastly more significant problem: the relationship betwen energetic events on the Sun and climate and weather on Earth.

Sun, Climate, and Weather

The direct effects of the Sun on climate and weather are so obvious we take them for granted: night and day, the change of seasons, wind direction and the movement of weather systems at different latitudes, surface water evaporation and rainfall. It is the secondary and more subtle effects, of which the three just mentioned are examples, which we need to understand.

We *think* the Sun-climate-weather relationship is very close because a tantalizing array of circumstantial evidence is beginning to come in, but no clear cause-effect chain has been established—yet. Consider the evidence.

In many areas of the world the amount of rainfall varies with the 11-year sunspot cycle, with more than average rainfall in equatorial regions and less than average in the middle latitudes at times of solar maximum (when the number of sunspots and the area of the Sun they cover are at a maximum).

Global surface temperatures vary with the sunspot cycle. Between 1804 and 1919 mean annual temperatures were lower at sunspot maximum than at minimum, and the same effect was recorded for the northern hemisphere alone between 1880 and 1968.

A related piece of evidence is that more rain falls in solar maximum years. More rain means more clouds. Clouds reflect the Sun's radiant energy better than the ground so that less heat gets into the atmosphere and surface temperatures drop.

Atmospheric pressure at the surface of the Earth not only varies with sunspot numbers but is affected by solar flares. Pressure readings tend to be lower than

normal near sunspot maximum in equatorial regions and higher than normal in the temperate zones. Surface pressures decrease in some areas and increase in others two to four days after a major flare.

In some areas of the world, especially in the higher latitudes both North and South, there is a clear relationship between numbers of sunspots and numbers of thunderstorms per year. In addition, the total number of thunderstorms occurring on Earth increases by 50 to 70 percent about four days after the eruption of a major flare on the surface of the Sun. In the United States there are more thunderstorms than usual at the time of the weekly change in the polarity of the Sun's magnetic field (the same change which frustrates our weather forecasters.)

Finally, there is the regular 22 year cycle of droughts in the high plains of the United States, which occur every other period of minimum sunspot activity on the Sun, and correlate directly with the 22 year cycle of solar magnetic polarity changes.

Taken together that is at least enough evidence to convince the most conservative scientist that further investigation is warranted. And that is exactly what we will be doing in the decade of the eighties—and beyond.

The Further Future

Although what we will be doing beyond the eighties becomes increasingly speculative and murky, we do have the benefit of some very highly educated guesses and suggestions. In June of 1980, the NASA Advisory Council organized a symposium at Woods Hole, Massachusetts to meet the recognized need for "new, vital, innovative, long-range space programs." One of the areas of interest considered by a symposium panel of scientists and engineers from NASA (including the NASA Administrator and former Chief Scientist), industry and the academic community, was "solar physics and solar-terrestrial interactions." At the end of a week of study and consultation, the panel came up with six bold, innovative and specific proposals which together give us the best estimate available of how the quest for knowledge might go forward in the years beyond the eighties.

First on the list was a series of satellites called "Centurion" to monitor and measure certain phenomena of both Sun and Earth with little or no human care or attention for 100 years. Once launched and on station, the Centurions would thus be unaffected by annual budget decisions, the waxing and waning of government agencies, changes in national policy, or individual scientific professional lifetimes. They would concentrate on those phenomena which could teach us the most from long-duration observation. Some of these are the solar constant—the radiance of the Sun in all wavelengths of the electromagnetic spectrum (first priority)—the solar wind, the flux or rate of flow of cosmic rays, changes in amounts and distribution of ozone and carbon dioxide in the Earth's atmosphere, changes in the total reflectivity of the whole Earth (its albedo), and in the amounts of infrared radiation from the Earth. Separate satellites would monitor each phenomenon with maximum reliability, simplicity and economy.

The Centurion's self-calibrating instruments would store their data on board in case of long neglect from the ground and transmit them at the demand of simple ground equipment either visually by flashing light or by slow radio telemetry.

The second suggestion was for a Solar Beacon to study changes in the shape of the Sun and provide detailed, high-resolution information about the features and events on the solar surface in a novel and relatively economical way. Solar Beacon would consist solely of a precisely flat circular mirror one meter (39 inches) in diameter rotating three times a minute in geostationary orbit (36,000 kilometers of 22,300 miles above the equator where its orbital speed exactly equals the rotational speed of the Earth so that it remains apparently stationary above a given location). The mirror would reflect a "pin-hole" image of the Sun 400 kilometers in diameter on the surface of the Earth where the changes in the diameter of the Sun could be measured night or day, by a line of one-meter-diameter light collectors. To an observer on Earth, Solar Beacon would look like a flashing first magnitude star.

The third idea to come from the symposium panel envisioned a spacecraft in Sun-stationary orbit (comparable to the geostationary orbit described above) at a distance of 1/6 AU equipped with a solar optical telescope, an x-ray telescope, and instruments for observing the corona and for measuring the emission of gamma rays and the solar wind. This spacecraft would remain on station for one full 11-year solar cycle.

Next on the Woods Hole list was a logical successor to the Solar Polar Mission with its one-time pass out of the ecliptic and over the solar poles. Labelled the Global Solar Mission, this would be a system of three spacecraft equally spaced (120 degrees apart) in an orbit around the Sun in the plane of its poles, or normal to the plane of the ecliptic, at a distance of one AU.

In the same way that communications and weather satellites spaced at 120 degree intervals around the Earth can collectively and continuously "see" the entire surface of the planet, the Global Polar Mission would keep the entire Sun under observation with identical instruments. Additionally, at any given moment half of the solar surface would be visible to two of the spacecraft making possible stereoscopic measurements and intercalibration of the observing instruments. In this way the mission would provide data over a full solar cycle on the Sun's magnetic field, the structure of the corona and characteristics of individual active regions on the surface.

The final pair of ideas to come from the panelists was equally imaginative. The first conceived of spacecraft, appropriately called Solar Scorchers, which would pass extremely close to the solar surface or even plunge directly into the otherwise unobservable solar interior itself.

Two missions were suggested for the "Scorchers." One, a close grazer or "gravity orbiter" would use the same slingshot effect from Jupiter as the Solar Polar flights but then be slowed by retrorockets into a 32-day orbit around the Sun with a closest point (perigee) just above the solar surface (the photosphere) and a high point (apogee) of .2 AU. The second, or Solar Plunger, would simply use Jupiter's gravity to fall straight into the Sun, directly measuring pressures, densities, temperatures and chemical compositions of the inner corona, chromosphere, and photosphere before its inevitable evaporation in the 29 million degree temperatures of the upper convection zone.

Together the Scorchers could test our theories of what happens in the solar interior (and therefore in the interiors of all stars), and perhaps solve the persistent puzzle of the observed neutrino deficiency.

As in the case of the Solar Probe planned for the middle eighties, Scorcher

designers would be faced with staggering problems of insulation against ultra-high temperatures and radiation as well as communications through the very noisy electromagnetic environment of the Sun. In a wonderfully optimistic piece of scientific understatement, the Woods Hole panelists "presumed that these obvious technical difficulties could probably be solved by a moderate extension of present engineering capabilities."

The final item on the list is an extrapolation of the use of tracer chemical releases in the Earth's environment, such as the release of barium to measure the flow of solar wind particles into the magnetosphere. It envisions the release of about 1000 kilograms (2200 pounds) of fluorine "with a definite upward velocity" at a chosen point in the Sun's corona which would then be carried outward on the solar wind and tracked by an Earth-orbiting telescope.

"What's in it for Me?"

Suppose that the suggestions of the Woods Hole panel were followed, or that roughly comparable projects in the study of Sun-Earth relations were accomplished as we expect they will be. What will it mean to the citizens of the United States of America and other residents of the planet Earth?

There are two parts to the answer. The first part is speculative, with the validity of the speculation decreasing down the vistas of the future. We can, however, reasonably expect to understand the nature of Sun-Earth relationships and of the Earth's environment in space with sufficient clarity to enable us to predict climate changes and the changed weather patterns associated with them far enough in advance to permit planning which takes those changes into account. For example if we know the growing season in Nebraska or Siberia will be shorter next year, we can plant or harvest earlier, or change fertilization methods, or plant faster-growing or different crops, or arrange in advance to import grain from areas where good growing conditions are predicted and where therefore more land has been planted. If we know there will be less rainfall in a given area, we can plant crops which require less moisture or arrange for increased irrigation, storing water in advance for the purpose. If we know that next winter there will be lots of snow in the Rockies and hardly any in New England, winter resorts in Colorado can expand to take advantage and those in Vermont retrench and wait for a better year. Pick your own illustrations from the myriad available.

With the ability to predict climate will come greatly improved ability to forecast weather. Detailed and accurate forecasts for periods up to a week are not unreasonable to expect.

After understanding and prediction, the next logical step is the beginning of an ability to control both climate and weather, with all the obvious advantages and equally obvious problems and complexities such a capability would bring.

With an accurate understanding of the interactions of solar energy with magnetosphere, ionosphere, stratosphere and atmosphere, and of the effects of human activities on those processes, can come the very necessary ability to maintain the health and integrity of that complex system, minimizing or eliminating those activities which damage it, such as loading it with carbon dioxide or fluorocarbons. Increased understanding could even give us the ability to "repair" damage already done to our space environment, restoring

it to its natural condition under which life on Earth evolved.

There is even the possibility, far in the future, that this kind of planetary environmental engineering might enable us over a long period of time to alter the atmosphere of another planet (Mars is the most logical candidate) to make it habitable by man.

A Fusion Future?

Perhaps the ultimate boon to mankind possible to derive from studies of the Sun is the unlocking of the secret of the nuclear fusion process which powers it, and the powerful magnetic phenomena associated with that process. If we can learn to create and control the nuclear fusion reaction we will have learned to use the energy source of the stars, an energy source which uses as fuel the original and still the most abundant element in the Universe—hydrogen, which releases no chemical pollutants, almost no radioactive waste and no residue at all except helium which is harmless, valuable and useful. A practical nuclear fusion reactor would extract from a gallon of sea water an energy value equal to 300 gallons of gasoline at a cost of a few cents a gallon for fuel. Taming the fusion process would give us a supply of clean, harmless electrical energy which would last as long as the Sun itself

We are working on fusion reactors. Some are well along in development. The basic problem is how to contain the 100-million degree temperature of the reaction, which would obviously vaporize any conceivable container material. The best way seems to be to "build" a container of magnetic fields—which happens to be precisely the way it is being done in the Sun at this and every other moment.

The benefits of the general use of fusion-generated electrical power are nearly incalculable but include as a minimum the end of atmospheric pollution with the carbon dioxide of burned fossil fuels, an end to the generation of dangerous and long-lived nuclear wastes from fission reactors, and a general improvement of the standards of living and the quality of human life worldwide. In addition, the availability of unlimited energy would strongly tend to reduce international competition for shrinking fossil fuels and thus the threat of thermonuclear annihilation which presently clouds the future of humanity.

We thus find ourselves faced with the incredibly elegant irony and the increasingly urgent challenge of a single physical process which gave us life in the first place and which now holds both the best hope for our future and the gravest threat to our survival.

That is one part, the speculative part, of the answer to the question, "What will all of this mean to us?"

Prospects Unpredictable

The second part of the answer is simply that we don't know. We don't know because we cannot predict the ways in which the knowledge in the storehouse will be used, combined, assembled, integrated, focused, in the future. The only certainty is that the knowledge *will* be used, and that the ways in which it is used will enhance the capabilities of mankind.

When Heron of Alexandria in the second or third century B.C. discovered that water heated into steam expands tremendously and exerts force, he could not possibly have predicted the great engines and steam turbines of today.

When the German physicist William Conrad Roentgen discovered x-rays in 1895, he could not possibly have predicted their present general use in medical diagnosis and therapy nor the human suffering they have prevented or allayed.

When, in the 1950s, a young graduate student in astronomy worked out the mathematics for an array of small antennas integrated by computer to act as a single very large one to receive weak radio signals from distant spacecraft, he could not have foreseen that those same mathematics would become the basis for the Computerized Axial Tomography machine or "CAT scanner"—a major medical breakthrough which provides detailed, three-dimensional maps of the brain and other organs more accurately and without the potential damage of conventional x-ray techniques.

Each generation in its own time adds its quota of knowledge to the treasure house of humanity for use by those which come after. The history of science teaches the inestimable value of the pursuit of the intellectually important, the intellectually challenging and exciting, because out of that effort, sooner or later, huge benefits will accrue to mankind. The Cro-Magnon antler-notcher, wondering at the Moon from some forest clearing when he should have been hunting the wooly mammoth to feed his family, was the first known scientist because he was the first known astronomer. Out of the need to explain astronomical phenomena was born mathematics, the foundation of science. And from science comes the technology of the modern world.

It is because we have learned that lesson from the history of science that the ISEE's and Solar Max spread their solar panels to the Sun and rifle back to Earth their streams of coded data, that the Solar Polar flights will soon be flung far out of the plane of the ecliptic and around the unknown poles of the Sun, that the automated laboratories of OPEN will one day stitch the Earth's magnetosphere, weaving a new fabric of knowledge for mankind, and that the daring concepts of the Woods Hole scientists are working their way through the system to reality.

All this is as it has always been. The lesson is not new. The whirling spacecraft, the giant mountain-top observatories, the sounding rockets piercing up to space, the instrument packages borne high aloft in aircraft and balloons, all are direct descendants of Stonehenge and Chaco Canyon, Casa Grande and the medicine wheels, Galileo's telescope and Newton's prism, Tyco Brahe's meticulous observations and Kepler's laws. All at one time were at the point of the search for knowledge. Now we are there, armed with the potent new weapon of access to space. It is our responsibility to the past and the future to use it wisely and well; to satisfy the need to know inherent in mankind.

It is also our good fortune to be involved in what well may be the greatest scientific and intellectual adventure of all.

Following page: The Solar Telescope of Skylab took this picture of the Sun. The Outer Corona: The Ethereal Sun-The Sun's corona stretches far beyond the denser, inner corona seen in X-rays and ultra-violet light, and beyond the limits of what we normally see in the dark sky of a total solar eclipse. Its farthest reaches are delineated by tapered streamers that stretch into interplanetary space, extending the domain of our nearest star much farther that its visible disk. We see the outer corona briefly at total eclipses of the Sun, where it appers white and delicate against the starry background of a temporarily darkened, daytime sky. Even then, Earth's intervening atmosphere is bright enough to limit our view of the outer corona. At Skylab's orbital altitude, where most no air was left and where the sky was starkly black, the outer corona was at last clearly seen. For 9 months it was continually observed by a coronagraph that blocked out the solar disk.

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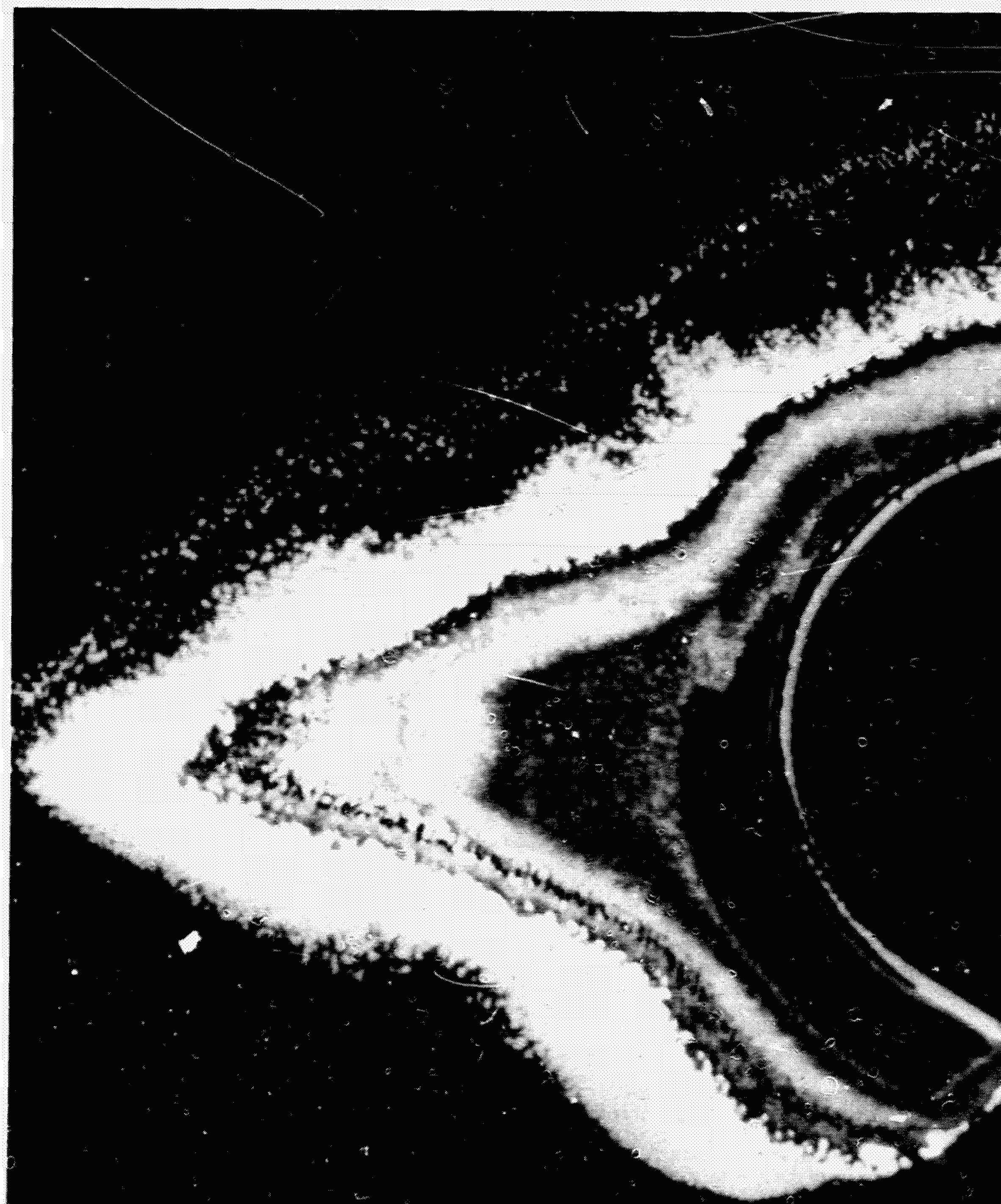

ORIGINAL PAGE
COLOR PHOTOGRAPH

SOURCES AND FURTHER READING

Chapter I

Alfven, Hannes. "Plasma Physics, Space Research, and the Origin of the Solar System" *Science*. Vol. 172, No. 3987, June 4, 1971.

Casson, Lionel: Claiborne, Robert; Fagan, Brian; and Karp, Walter, *Mysteries of the Past*. New York: American Heritage Publishing Company, 1977.

Daniel, Glyn. "Megalithic Monuments" *Scientific American*. Vol. 243, No. 1, July, 1980.

Eddy, John A. "The Maunder Minimum" *Science*. Vol. 192, No. 4245, June 18, 1976.

Eiseley, Loren. *The Immense Journey*. New York: Random House, 1957.

Frazier, Kendrick. "Stars, Sky and Culture" *Science News*. Vol. 116, August 4, 1979.

Friedman, Herbert. "The Sun" *National Geographic*. Vol. 128, No. 5, November, 1965.

Lanzerotti, L. J. (ed.) "Impacts of Ionospheric/Magnetospheric Processes on Terrestrial Science and Technology" *Space Plasma Physics: The Study of Solar-System Plasmas*. Vol. 2, *Working Papers*. National Academy of Sciences, Washington, D.C., 1979.

Prideaux, Tom. *The Emergence of Man*. Cro-Magnon Man. Alexandria, Virginia: Time-Life Books, 1973.

Sagan, Carl. *Cosmos*. New York: Random House, 1980.

Stafford, Edward P. *The Far and the Deep*. New York: G. P. Putnam's Sons, 1966.

Chapter II

A New Sun: The Solar Results from Skylab. NASA SP-402. Washington D.C.: U.S. Government Printing Office, 1979.

Atoms and Astronomy. NASA EP-128. Washington, D.C.: U.S. Government Printing Office, 1976.

Canby, Thomas Y. "Skylab, Outpost on the Frontier of Space." *The National Geographic Magazine*. Vol. 146, No. 4, October, 1974.

Chemistry Between the Stars. NASA EP-127, Washington, D.C.: U.S. Government Printing Office, 1976.

Exploration of the Solar System. NASA EP-122. Washington, D.C.: U.S. Government Printing Office, 1974.

Hinners, Noel W. *Statement before the Subcommittee on Space Science and Applications of the Committee on Science and Technology of the House of Representatives*. Washington, D.C., September 26, 1978.

Mission Operation Report: Helios B. NASA Office of Space Science Report No. S-823-76-02. Washington, D.C.: Executive Management Services Division, NASA Headquarters, December 30, 1975.

NASA Press Kit, Release No. 78-118. Project ISEE 3. Washington, D.C. NASA Headquarters, August 4, 1978.

NASA Release No. 79-161: Solar Maximum Mission. Washington, D.C.: NASA Headquarters, November, 1979.

Pioneer: First to Jupiter, Saturn, and Beyond. NASA SP-446. Washington, D.C.: U.S. Government Printing Office, 1980.

Skylab and the Sun. NASA EP-119. Washington, D.C.: U.S. Government Printing Office, 1973.

"Solar Mission Will Pace Modular Spacecraft Idea." *Aviation Week and Space Technology*, January 19, 1976.

"The Secrets of the Sun." *Newsweek*. October 13, 1980.

Thompson, Dietrick E. "A Flair for the Sun." *Science News*. Vol. 118, No. 10, September 6, 1980.

Chapter III

Hinners, Noel W. *Statement Before the Subcommittee on Science, Technology and Space, of the Committee on Commerce, Science and Transportation, United States Senate.* Washington, D.C., February 28, 1979.

NASA Program Plan, Fiscal Years 1981 Through 1985. NASA Headquarters, Washington, D.C., January 1980.

Origin of Plasmas in the Earth's Neighborhood. NASA, Goddard Space Flight Center, Greenbelt, Maryland, 1980.

Solar Terrestrial Programs. A Five-Year Plan. Solar Terrestrial Division, Office of Space Sciences, NASA Headquarters, Washington, D.C., August 1978.

Chapter IV

A Forecast of Space Technology. NASA SP-387, Washington, D.C.: U.S. Government Printing Office, 1976.

Brown, William M. and Kahn, Herman. *Long-Term Prospects for Developments in Space (A Scenario Approach).* NASA CR-156837. Croton-on-Hudson, New York: Hudson Institute, Inc., October, 1977.

Favale, Anthony. "Exploring Energy Frontiers." *Horizons.* Vol. 16, No. 1, 1980.

Gottleib, Melvin. "An Energy Overview." *Vital Speeches of the Day.* Vol. XLV, No. 19, July 15, 1979.

Report of the Discussions at the NASA Advisory Council's New Directions Symposium, Woods Hole, Massachusetts. June 9-14, 1980.

Sun, Weather and Climate. NASA SP-426. Washington, D.C.: U.S. Government Printing Office, 1978.

The Next Billion Years. Ames Research Center, NASA. Moffet Field, California, August, 1974.

The Quiet Sun. NASA SP-303. Washington, D.C.: U.S. Government Printing Office, 1972.

Understanding Climatic Change. A Program for Action. Washington, D.C.: National Academy of Sciences, 1975.

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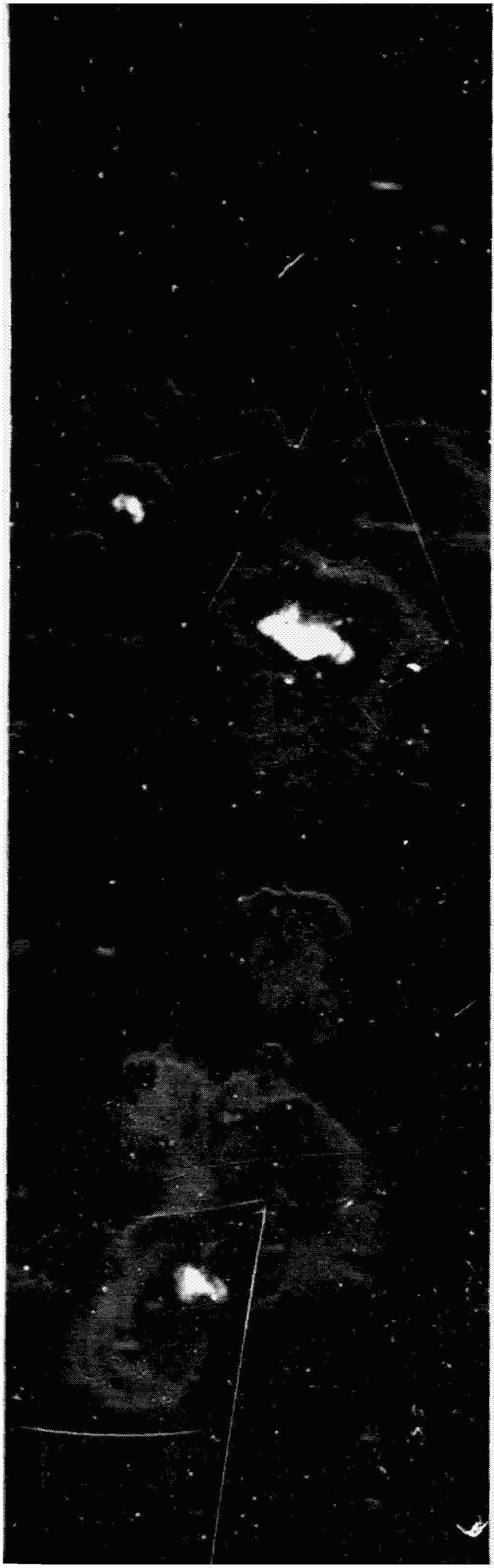
Edward Peary Stafford is a writer and former Naval Aviator living in Timonium, Maryland. He has published two books of naval history, and written for Readers Digest, Smithsonian, Naval Institute Proceedings, National Geographic and other periodicals.

Note:
In addition to the publications listed above, an indispensable source of information on most topics covered in this publication was a series of taped interviews with Dr. Erwin R. Schmerling of NASA's Solar Terrestrial and Astrophysics Division.



ORIGINAL PAGE
COLOR PHOTOGRAPH

Skylab's Solar Telescope took this picture of solar prominences. The ultraviolet solar data was reduced to graphic imagery using a computerized color enhancement process, first applied to Skylab Solar Telescope imagery.

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